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Washington DC 20460

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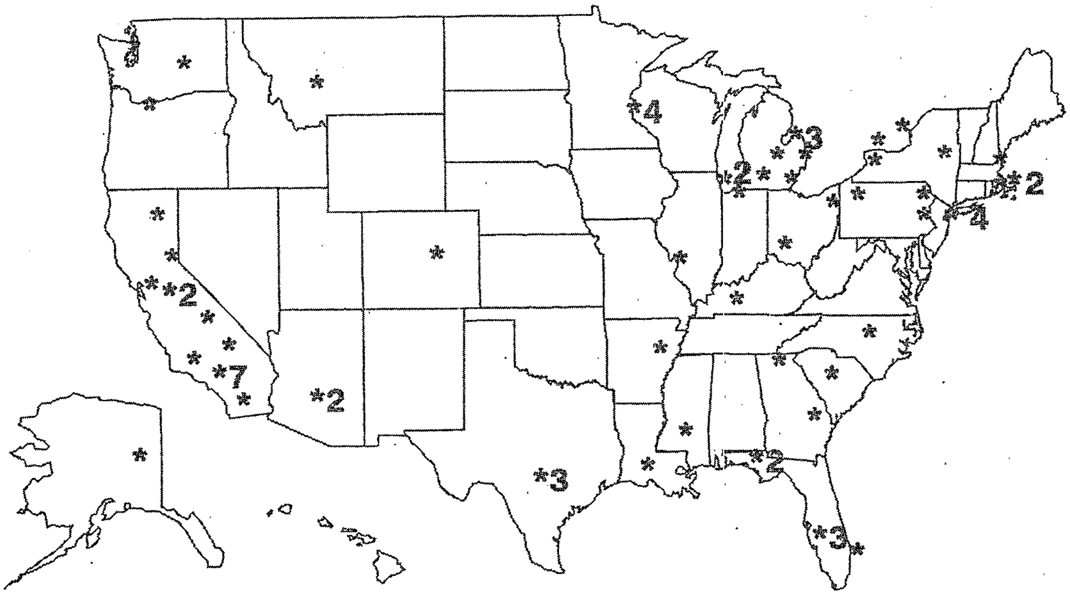
December 1994

EPA

SITE Program: An Engineering Analysis of the Demonstration Program

SITE Demonstration Locations



70 Completed Demonstrations

SITE

SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

EPA/540/R-94/530
December 1994

SITE PROGRAM

AN ENGINEERING ANALYSIS OF THE DEMONSTRATION PROGRAM

Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Printed on Recycled Paper

Notice

The information in this document has been prepared for the U.S. Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) Program under Contract No. 68-C0-0047. This document has been subjected to EPA's peer and administrative reviews, and approved for publication as an EPA document. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

Foreword

The Superfund Innovative Technology Evaluation (SITE) Program was authorized in the 1986 Superfund Amendments and Reauthorization Act. The SITE Program is a joint effort of the U.S. Environmental Protection Agency's (EPA) Office of Research and Development (ORD) Risk Reduction Engineering Laboratory (RREL), and EPA's Office of Solid Waste and Emergency Response (OSWER). The SITE Program was created to evaluate and assist the development of innovative technologies relevant to hazardous waste problems, especially those that offer permanent remedies for contamination commonly found at Superfund and other hazardous waste sites. The SITE Program evaluates innovative treatment and monitoring and measurement methods through technology demonstrations designed to provide engineering and cost data for the selected technologies. These demonstrations occur in the SITE Demonstration Program and the SITE Monitoring and Measurement Technologies Program, respectively.

The SITE Program has conducted more than 60 field demonstrations of innovative treatment or monitoring and measurement technologies to date. Over 100 participants have demonstrated or are currently demonstrating their technologies for SITE Program evaluations. The SITE Demonstration Program provides environmental decision-makers with data on new, viable treatment technologies that may have performance or cost advantages compared to conventional remediation technologies. At the conclusion of each demonstration, EPA produces and distributes reports documenting demonstration data and the potential applicability of the demonstrated technology.

This Engineering Analysis summarizes the information from all SITE Demonstration Program reports completed to date. A limited number of copies of this report will be available at no charge from EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268, (513) 569-7562. Requests for copies should include the EPA document number found on the report's cover. When this supply is exhausted, additional copies can be purchased from the National Technical Information Service, Ravensworth Building, Springfield, Virginia 22161, (703) 487-4600. Reference copies will be available at EPA libraries in the Hazardous Waste Collection.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

Abstract

This report documents an engineering analysis of the Superfund Innovative Technology Evaluation (SITE) Demonstration Program performed between February 1993 and April 1994. The SITE Program evaluates new and promising treatment and monitoring and measurement technologies for cleanup of hazardous waste sites through its Demonstration Program and its Monitoring and Measurement Technologies Program. Analyses of 36 remediation technology demonstrations from data in published and draft SITE Demonstration Program reports are included. This analysis also considers additional material contained in those reports, including case studies of the technologies provided by their developers, but not evaluated by the SITE Program. Performance and cost information for conventional remediation technologies is included for comparison.

This report is divided into ten sections. Section 1 introduces the SITE Program. Section 2 discusses the applicability of innovative technologies to various environmental media and hazardous waste constituents. Sections 3 through 9 compare innovative remediation technologies demonstrated in the SITE Program to conventional alternatives for the following technology types: thermal destruction, thermal desorption, solidification/stabilization, biological treatment, physical/chemical treatment, materials handling, and radioactive waste technologies. Section 10 discusses SITE Program accomplishments and future challenges, and advancements needed in the hazardous waste remediation technology market.

Tables in each section compare the applications and costs of innovative and conventional technologies. The text briefly describes each technology, available SITE Program demonstration results, and advancements in each technology area. SITE Program reports from each technology demonstration and additional EPA reports on remediation technology types are referenced.

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Acknowledgments

This report was prepared under the direction and supervision of Mr. Donald Sanning, U.S. Environmental Protection Agency (EPA) Senior Scientist in the Superfund Technology Demonstration Division (STDD) of the Risk Reduction Engineering Laboratory (RREL), Cincinnati, Ohio. Contributors and reviewers for this report were Mr. E. Timothy Oppelt, Mr. Robert A. Olexsey, Mr. John Martin, Ms. Annette Gatchett, and Mr. Gordon Evans of EPA RREL.

Materials for this report were provided by the EPA's Superfund Innovative Technology Evaluation (SITE) Program, the STDD Technical Support Branch, and the Office of Solid Waste and Emergency Response (OSWER) Technology Innovation Office (TIO). Three contractors support the SITE Program by developing data and preparing reports: Science Applications International Corporation (SAIC), Foster Wheeler Enviresponse, Inc. (FWEI), and PRC Environmental Management, Inc. The efforts of SAIC and FWEI staff in supplying information for this document are gratefully acknowledged.

This report was prepared for EPA's SITE Program by PRC Environmental Management, Inc. under Contract No. 68-C0-0047.

1.0 SITE PROGRAM DESCRIPTION

U.S. Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) program, was established in 1986 to encourage the development and use of innovative treatment technologies and innovative measurement technologies at hazardous waste sites. The SITE Program was established by EPA's Office of Solid Waste and Emergency Response (OSWER) and the Office of Research and Development (ORD) in response to the 1986 Superfund Amendments and Reauthorization Act (SARA), which recognized a need for an alternative or innovative treatment technology research and demonstration program. While it was initiated to serve Superfund legislation, the SITE Program provides valuable information for use in remediating hazardous waste sites under Superfund, the Resource Conservation and Recovery Act (RCRA) and other cleanup legislation.

The SITE Program includes the following component programs:

- **Demonstration Program** - Conducts and evaluates demonstrations of promising innovative treatment technologies to provide reliable information on their performance, cost and applicability.

- **Emerging Technology Program** - Provides funding to developers to continue developmental efforts from the bench- and pilot-scale levels to promote the full-scale use of innovative treatment technologies

- **Monitoring and Measurement Technologies Program** - Evaluates innovative technologies that detect, monitor, and measure hazardous and toxic substances to provide better, faster, and more cost-effective methods for producing real-time data during site characterization and remediation

- **Technology Transfer Activities** - Disseminates technical information on innovative technologies to assist in removing impediments to using these technologies

The SITE Program is administered by ORD's Risk Reduction Engineering Laboratory (RREL), headquartered in Cincinnati, Ohio. This document specifically evaluates and summarizes the innovative treatment technologies which have been demonstrated by RREL under the SITE demonstration program. This document was prepared as an engineering review of the technologies evaluated under SITE since the beginning of the program. This report is designed to be a compendium of current information on innovative technologies and vendors for completed demonstrations. Information was obtained from draft and final AARs for demonstrations completed to date; from technology vendors; and from personal communication with SITE project managers. Every effort was made to update and clarify the engineering data associated with the technologies.

1.1 SITE DEMONSTRATION PROGRAM

The SITE demonstration program develops reliable engineering, performance, and cost data on innovative treatment technologies through rigorous testing and on a specific waste site. Data collected during a field demonstration are used to assess the technology's potential applicability and performance for a variety of waste and site conditions. The SITE Program does not certify or approve technologies for use at hazardous waste sites. Rather, it provides detailed information to those making decisions concerning which technologies to use on their sites.

For each completed SITE demonstration, EPA prepares a report that evaluates the specific technology and analyzes its overall applicability to the site characteristics, waste types, and waste matrices or other sites. These Applications Analysis Reports (AAR), recently reformatted and renamed the Innovative Technology Evaluation Reports (ITER), are the primary technology transfer products of the SITE demonstration program. Other reports, including the Technology Evaluation Report (TER), further describe the technology and its operating characteristics. Demonstration bulletins, project summaries, engineering capsule reports, and videotapes are also prepared after each demonstration.

Technologies are selected for the program primarily through annual requests for proposals (RFP). EPA reviews proposals to determine which innovative technologies have promise for use at Superfund and other sites where priority cleanup goals are not adequately addressed with reliable and cost-effective conventional technologies. EPA then invites selected technology developers to participate in demonstrations. In addition, other technologies, primarily those used for ongoing Superfund projects or private sector activities, may be identified for evaluation by EPA regional offices or other state or federal agencies.

The technology demonstration activities generally fall into three categories: predemonstration or planning, field demonstration, and postdemonstration analysis and evaluation. These activities are listed in Table 1-1 along with responsible or participating organizations.

1.2 QUALITY ASSURANCE OBJECTIVES AND AUDITS

The quality assurance objective for a SITE demonstration is to produce results that complement other data that could be used to make decisions concerning remedial activities. RREL Category 2 quality assurance is typically used for SITE demonstrations. Quality is measured by the data's precision, accuracy, completeness, representativeness, comparability, and target reporting limits for the analytical methods. Detailed quality assurance project plans (QAPP) are prepared for each demonstration to insure that appropriate and valid data are collected to meet technology and site-specific project objectives.

EPA audits both the field demonstration and the laboratory analysis to verify that:

- Sampling, analytical, and quality control procedures from the approved QAPP are properly implemented

- Modifications to the approved procedures are appropriate to resolve problems encountered in the field or laboratory

1.3 ENGINEERING SURVEY

Following this introductory section, the report is organized into sections dealing with specific technology categories: thermal destruction, thermal desorption, solidification/stabilization, biological treatment, physical/chemical treatment, materials handling, and radioactive waste treatment. Each section includes a brief overview of the technology category and a set of tables listing demonstration results and other data. Basic information concerning the technology demonstration, such as location, matrix, hazardous constituents tested, and test results are presented in one table. Engineering data concerning application, unit cost, and limiting factors are presented in a second table for each innovative treatment technology. A short narrative is included to present important information on the contribution of each demonstration to the field of environmental treatment technologies. This document will provide the reader with a means of matching a given hazardous waste problem with the appropriate innovative technology type for that waste.

TABLE 1-1

TECHNOLOGY DEMONSTRATION ACTIVITIES

Predemonstration Activities	Responsible Organizations
Site selection	EPA ORD, EPA regions, state agencies, and developer
Waste characterization	EPA ORD, EPA regions, and state agencies
Treatability testing	EPA ORD and developer
Demonstration plan preparation	EPA ORD
Site preparation	EPA ORD
Equipment mobilization	Developer
Demonstration Activities	
Equipment operation	Developer
Process monitoring and measurement	EPA ORD and developer
Sample collection onsite	EPA ORD
Photo documentation	EPA ORD

TABLE 1-1 (continued)

TECHNOLOGY DEMONSTRATION ACTIVITIES

Demonstration Activities	Responsible Organizations
Quality assurance field audits	EPA ORD
Visitors' Day and other community relations activities	EPA ORD, EPA regions, state and local agencies, developer, community groups and other interested parties
Postdemonstration	
Equipment demobilization	Developer
Site restoration	EPA ORD
Laboratory analysis	EPA ORD
Quality assurance laboratory audit	EPA ORD
Technology performance and cost evaluation	EPA ORD
Technology transfer (bulletins, reports, videotape, and conferences	EPA ORD, developer

2.0 TECHNOLOGY APPLICABILITY TO WASTE TYPES

This section provides an overview of the types of treatment technologies demonstrated and evaluated under the SITE Program, and the types of hazardous wastes to which they are applicable.

The SITE Program has demonstrated 56 treatment technologies on Superfund sites, at RCRA facilities, and on real or simulated wastes at EPA, developer, or other research facilities. These demonstrations provide a collection of information on the performance of individual technologies and on the general treatment categories in which they fit. Furthermore, the SITE Program encourages developers to submit the results of other trial or field work as case studies. By examining this information, a larger collection of information regarding waste applicability has been developed.

Hazardous waste problems can be categorized in many different ways. Under Superfund, a site is generally typified by the activities formerly performed there. Under RCRA legislation, wastes are categorized by the origins of the waste material or by the characteristics of the waste material. Other systems (for example, the U.S. Army Corps of Engineers) may simply identify the predominant contaminants and waste matrix (or medium). For example, it may be appropriate to identify a hazardous waste problem simply as "cyanide in groundwater" or "trichloroethylene (TCE) and perchloroethylene (PCE) in subsurface soils and groundwater." Certain contaminants are frequently grouped under a single title. For example, anthracene, fluorene, phenanthrene, chrysene, benzo(a)pyrene, and others are grouped as polynuclear aromatic hydrocarbons (PAHs) or "EPA Priority PAHs." Some contaminants may fit into more than one grouping, and different organizations may have different groupings (for example, U.S. Army Corps of Engineers, various states). Similarly, hazardous wastes may appear in several different media or matrices at a site. Terms such as soil, sediments, and sludge may have different meanings when used by different agencies or authors.The SITE Program generally specifies contaminant type and waste medium or matrix in order to facilitate communication within any waste identification system.

2.1 HAZARDOUS WASTE PROBLEMS AND APPLICABLE TECHNOLOGIES

The SITE Program has performed evaluative demonstrations of seven types of innovative treatment technologies designed to treat a variety of hazardous wastes. During SITE demonstrations, all data regarding cost and technical performance of the technology were obtained and analyzed by EPA. The developers of these technologies presented SITE with additional information concerning their treatment experiences with other waste types. Taken together, this data allows for some conclusions to be drawn concerning various types of innovative technologies and the hazardous waste situations for which they may be applicable. Before planning any full-scale remediation, it is always recommended that a feasibility study and a treatability study be conducted in order to verify the cost-effectiveness and implementability of the preferred technology, and to verify that remediation goals can be met for the site and waste type in question.

Table 2-1 shows the types of contaminants and media examined during SITE Program demonstrations and the technology types which were evaluated with those wastes. This information can be used to begin identifying appropriate treatment technologies for a given hazardous waste problem. Sections 3 through 10 of this document summarize specific information on the SITE demonstration program innovative treatment technologies. Readers are referred to the appropriate individual SITE Program reports to further investigate the performance of a specific technology on a given waste type.

TABLE 2-1

HAZARDOUS WASTES AND APPLICABLE TECHNOLOGIES AS DEMONSTRATED BY THE EPA SITE PROGRAM

	Thermal Destruction			Thermal Desorption			Solidification/ Stabilization			Biological Treatment			Physical/ Chemical Treatment			Materials Handling			Radioactive Waste Technology		
Waste	S	L	G	S	L	G	S	L	G	S	L	G	S	L	G	S	L	G	S	L	G
VOCs	D	#	#	D	o	o	D	o	o	•	•	#	D	D	D	D	D	o	o	o	o
SVOCs	D	#	#	D	o	o	#	o	o	•	•	o	D	D	o	#	#	o	o	o	o
Halogenated organics	D	#	#	D	o	o	D	o	o	D	D	o	D	D	D	•	o	o	o	o	o
PCBs	D	#	o	D	o	o	D	o	o	•	•	o	•	•	o	o	o	o	o	o	o
PAHs	#	#	o	•	o	o	#	o	o	D	•	o	D	D	o	#	#	o	o	o	o
Heavy metals	D	#	o	o	o	o	D	•	o	o	o	o	D	D	o	o	o	o	o	o	o
Organics	D	D	o	•	o	o	D	•	o	•	•	•	•	•	o	o	o	o	o	o	o
Inorganics	D	#	o	o	o	o	D	o	o	o	o	o	•	D	o	o	o	o	o	o	o
Lead, zinc	D	#	o	o	o	o	D	o	o	o	o	o	#	o	o	o	o	o	o	o	o
Pesticides	D	#	#	D	o	o	o	o	o	D	o	o	D	•	o	#	#	o	o	o	o
Petroleum hydrocarbons	D	#	#	•	o	o	D	•	o	D	D	o	D	•	o	#	#	o	o	o	o
Radionuclides	D	o	o	o	o	o	o	o	o	o	o	o	#	•	o	o	o	o	o	D	o

Note: S = Solids, L = Liquids, G = Gases, D = SITE Demonstration waste, • = Data supplied by technology developer, # = No data, technology believed to succeed when performed by experienced developers, o = No available information.

Source: U.S. Environmental Protection Agency (EPA). 1993. The Superfund Innovative Technology Evaluation (SITE) program. Technology Profiles. Sixth Edition. Office of Research and Development. EPA/540/R-93/526. November.

3.0 THERMAL DESTRUCTION

Thermal destruction technologies are classified by the type of combustion chamber. The common types include: rotary kilns, multiple hearth chambers, and fluidized beds. Innovative thermal destruction treatment technologies focus on improving cost effectiveness, efficiency, and environmental safety by modifying or enhancing these proven waste treatment systems. Also, newly developed waste vitrification treatment systems are included in this category.

In thermal destruction systems, the contaminated material to be processed, or waste feed, is stored or prepared in some type of waste handling system. The waste feed then enters a combustion chamber, where it is oxidized and reduced to carbon dioxide, water, and acid vapor and ash. Air pollution control equipment, which may include afterburners, scrubbers, demisters, baghouses, and electrostatic precipitator, capture vapors and particulates leaving the combustion chamber. Residual wastes typically include slag or bottom ash from the combustion chamber, fly ash, and liquid wastes from air pollution control equipment. In vitrification systems the waste is converted into a glass-like material.

Additional information on thermal destruction technologies are found in EPA's Engineering Bulletin and Engineering Issue Paper numbers EPA/540/2-90/014, EPA/540/S-92/010, EPA/540/2-91/004, and EPA/540/S-92/014.

3.1 EVALUATION OF SITE TECHNOLOGY DEMONSTRATIONS

Five thermal destruction technologies have been demonstrated under the SITE Program. A summary of the SITE demonstrations is provided in Table 3-1, and a summary of the technology applications and cost information is provided in Table 3-2. Both tables follow this section. Information pertaining to the results or accomplishments of each SITE demonstration is summarized below.

American Combustion Inc. (ACI) developed the Pyretron Oxygen Enhanced Burner, which was demonstrated at EPA's Combustion Research Facility in Jefferson, Arkansas from November 1987 to January 1988. The ACI PYRETRON® technology controls the heat input into an incineration process by using PYRETRON® oxygen-air-fuel burners and controlling the level of excess oxygen available for oxidation of hazardous waste.

Babcock & Wilcox (B&W) developed the Cyclone Furnace Vitrification Technology, which was demonstrated in August 1992, at B&W's Research and Development Pilot Facility in Alliance, Ohio. B&W's cyclone furnace is designed for the combustion of high inorganic content (high ash) materials and has been used to vitrify wastes containing heavy metals, organic contaminants, and surrogate radionuclides. Surrogate radionuclides are nonradioactive metals that behave as radionuclide species in the cyclone furnace.

Horsehead Resource Development Company, Inc. (HRD), developed the Flame Slagging Reactor, which was demonstrated in March 1991 at HRD in Monaca, Pennsylvania. The HRD flame reactor system is a patented, hydrocarbon-fueled, flash-smelting system that treats residues and wastes containing metals and produces a nonleachable slag.

Retech, Inc., developed the Plasma Arc Centrifugal Treatment Furnace (PACT),which was demonstrated in June 1992 at the Department of Energy (DOE) Component and Integration Facility in Butte, Montana. The PACT vitrification process uses heat from a transferred plasma arc torch to create a molten bath that detoxifies the feed material, and melting and vitrifying the solids at 2,800 to 3,000 °F.

The Shirco Infrared Incineration System (now owned by Gruppo Italimpresse and available from several U.S. vendors) was evaluated in two SITE demonstrations. One demonstration took place in August 1987 at the Peak Oil Superfund Site in Brandon, Florida, and the other demonstration took place in November 1987 at the Demode Road Superfund Site in Rose Township, Michigan. Shirco's infrared thermal destruction technology is a mobile thermal processing system that uses electrically-powered silicon carbide rods to heat organic wastes to combustion temperatures. Any remaining combustibles are incinerated in an attached afterburner.

3.2 THERMAL DESTRUCTION TECHNOLOGY ADVANCEMENTS

The SITE demonstrations of thermal destruction technologies have shown that thermal destruction systems can effectively immobilize and decrease the leachability of inorganic compounds, thus decreasing reliance on air pollution control equipment to remove these compounds from stack emissions. These demonstrations also have advanced the development of both innovative destruction and destruction support technologies. For example, prior to participation in the SITE demonstration program, thermal destruction technologies such as Shirco's Infrared Incineration were considered unproven and were not used to remediate Superfund sites. Other incineration technologies demonstrated under the SITE Program, such as HRD's Flame Slagging Reactor and Retech's PACT, have expanded the range of thermal destruction to options other than conventional, fixed facility, rotary kiln technology.

A major drawback to thermal destruction is disposal of residual ash, which often requires stabilization treatment or disposal in a secured cell due to its leachability. The Babcock & Wilcox claim, that its Cyclone Furnace Vitrification technology immobilizes heavy metals and radionuclides in a nonleachable slag, was verified by the SITE Program. Similarly, Horsehead Resources Development Company claims that the Flame Slagging Reactor also immobilizes metal species. Both developers, as well as Retech (PACT) and Gruppo Italimpresse (Shirco Infrared Incineration) also claim high destruction efficiencies for organic compounds.

The SITE Program also has provided a forum for advancements in thermal destruction support equipment. American Combustion, Inc.'s Pyretron Oxygen Enhanced Burner equipment is designed to enhance the destruction efficiency of wastes. It has also been designed to decrease air emissions as explained in SITE's emerging technology program for Energy and Environmental Research Corporation's Reactor/Filter System and General Atomics' Acoustic Barrier Particulate Separator (EPA 1992h).

Future thermal destruction technology advancements may include increased transportability, greater immobilization/encapsulation, increased throughput, and increased destruction efficiency.

TABLE 3-1
SITE DEMONSTRATION TECHNOLOGIES SUMMARY
THERMAL DESTRUCTION

DEVELOPER/TECHNOLOGY/AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS	DEMONSTRATION RESULTS	REMOVAL EFFICIENCIES
American Combustion, Inc. (ACI) PYRETRON® Oxygen Enhanced Burner EPA/540/A5-89/008	November 1987 to January 1988 EPA's Combustion Research Facility in Jefferson, Arkansas	Sludge and soil waste mixture containing decanter tank tar sludge from coking operations (EPA hazardous waste code K087). <u>Feed Soil (ppm)</u> Naphthalene 62 Acenaphthylene 15 Fluorene 7.6 Phenanthrene 28 Anthracene 8.3 Fluoranthene 14	PYRETRON® system replaces the combustion air with oxygen. Oxygen enhancement reduces the combustion volume which results in increased throughput rates and greater residence time.	<u>Destruction Removal Efficiencies (DRE)</u> Naphthalene >99.99% Acenaphthylene >99.99% Fluorene >99.99% Phenanthrene >99.99% Anthracene >99.99% Fluoranthene >99.99% PYRETRON® system achieved DREs greater than 99.99% at feed rates double those for conventional incineration.
Babcock & Wilcox (B&W) Cyclone Furnace Vitrification Technology EPA/540/AR-92/017	August 1992 B&W Research and Development Pilot Facility in Alliance, Ohio	Synthetic soil matrix (SSM) was a well-characterized, granular material spiked with heavy metals, SVOC and surrogate radionuclides (SR). <u>Feed Soil (ppm)</u> Cadmium 1,260 Chromium 4,350 Lead 6,410 Bismuth (SR) 4,180 Strontium (SR) 3,720 Zirconium (SR) 4,070 Anthracene 4,710 Dimethyl-phthalate 8,340 Cadmium [TCLP] 49.9 Chromium (total)[TCLP] 2.64 Lead [TCLP] 97.3	<u>Treated Soil (ppm)</u> Cadmium 106 Chromium 1,610 Lead 1,760 Bismuth (SR) 730 Strontium (SR) 3,210 Zirconium (SR) 3,640 Anthracene <0.24 Dimethyl-phthalate <3.89 Cadmium [TCLP] <0.12 Chromium [TCLP] 0.22 Lead [TCLP] <0.31	DRE's for POHCs were greater than 99.99 percent. The quantities of POHCs in the stack gas were not measurable; therefore, the furnace obtained better than expected results. Simulated radionuclides were immobilized within slag according to standards. However, data regarding simulated radionuclides are suspect since the testing method has not been well-quantified or validated.

Source: U.S. Environmental Protection Agency (EPA). 1989a. American Combustion, Inc. PYRETRON® Destruction System. Applications Analysis Report. Office of Research and Development. June.
U.S. Environmental Protection Agency (EPA). 1992a. Babcock & Wilcox. Cyclone Furnace Vitrification Technology. Applications Analysis Report. Office of Research and Development. August.

TABLE 3-1 (Continued)

SITE DEMONSTRATION TECHNOLOGIES SUMMARY
THERMAL DESTRUCTION

DEVELOPER/TECHNOLOGY/AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS	HAZARDOUS CONSTITUENTS	DEMONSTRATION RESULTS
Horsehead Resource Development Company, Inc. (HRD) Flame Slagging Reactor EPA/540/A5-91/005	March 1991 Monaca, Pennsylvania	Feed Slag (ppm) Arsenic 0.0515 Cadmium 0.0411 Lead 5.41 Zinc 0.416 Arsenic [TCLP] 0.213 Cadmium [TCLP] 12.4 Lead [TCLP] 5.58 Dried and crushed rotary kiln secondary lead smelter (SLS) slag transferred from the National Smelting and Refining Company, Inc. (NSR), Superfund site in Atlanta, Georgia. SLS slag from the NSR site had a moisture content of up to 30 percent.	Treated Slag (ppm) / Oxide Product (ppm) Arsenic 0.0262 0.110 Cadmium 0.000373 0.128 Lead 0.552 17.4 Zinc 0.113 1.38 Arsenic [TCLP] 0.474 Cadmium [TCLP] <0.050 Lead [TCLP <0.330	DRE: >99.99% Flame Slagging Reactor achieved a net weight reduction of 36.6 percent when the waste feed was processed into oxide product and effluent slag.
Retech, Inc. Plasma Centrifugal Furnace (PCF) EPA/540/A5-91/007	June 1992 Department of Energy Component and Integration Facility in Butte, Montana	Test material consisted of a mixture of metal-bearing soil and No. 2 diesel oil. The mixture was blended to provide 10 percent by weight diesel oil and spiked to provide 982 ppm of zinc oxide and 972 ppm of hexachlorobenzene. Feed Soil (ppm) Calcium 175 Zinc 982 Hexachlorobenzene 972 Naphthalene 0.397 2 Methyl-naphthalene 0.282	Furnace evaluated during the demonstration test was a pilot-scale unit designated PCF-6. The feed rate for the PCF-6 is 120 pounds per hour (lb/hr). Calcium [TCLP] 2.22 Zinc [TCLP] 0.37 Hexachlorobenzene [TCLP] Not Detected Naphthalene [TCLP] Not Detected 2 Methyl-naphthalene [TCLP] Not Detected	DRE: >99.99%

Source: U.S. Environmental Protection Agency (EPA). 1992e. Horsehead Resource Development Company, Inc. Flame Reactor Technology. Applications Analysis Report. Office of Research and Development. May.
EPA. 1992f. Retech. Inc. Plasma Centrifugal Furnace. Applications Analysis Report. Office of Research and Development. June.

TABLE 3-1 (Continued)

SITE DEMONSTRATION TECHNOLOGIES SUMMARY
THERMAL DESTRUCTION

DEVELOPER/TECHNOLOGY/AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS		DEMONSTRATION RESULTS		REMOVAL EFFICIENCIES
Gruppo Italimpresse Shirco Infrared Incineration System (Shirco) EPA/540/A5-89/010	August 1987 Peak Oil Superfund Site in Brandon, Florida	Test material consisted of 7,000 tons waste oil sludge. The sludge was mixed with sand, soil, and lime to form a conditioned waste soil matrix.				
		<u>Feed Soil (ppm)</u>		<u>Treated Soil (ppm)</u>		
		PCB	4.63	PCB	0.423	
		Lead	5500	EPtox: Lead (EP tox)	31.250	
				TCLP Lead (TCLP)	0.013	DRE (PCB): >99.99%
	November 1987 Demode Road Superfund Site in Rose Township, Michigan	Test material consisted of 4,000 tons of soil described as dry, brown, sandy, and silty clay topsoil.				
		<u>Feed Soil (ppm)</u>		<u>Treated Soil (ppm)</u>		
		PCB	288.79	PCB	0.386	
		Lead (EP tox)	0.228	Lead (EP tox)	0.597	
		Lead (TCLP)	1.168	Lead (TCLP)	1.80	DRE (PCB): >99.99%
				Shirco met the Toxic Substance Control Act for PCB treatment standards		

Source: U.S. Environmental Protection Agency (EPA). 1989c. Shirco Infrared Systems, Inc. Shirco Infrared Incineration System. Applications Analysis Report. Office of Research and Development. June.

TABLE 3-2

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY THERMAL DESTRUCTION

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
American Combustion, Inc. PYRETRON®	PYRETRON® is an incineration "add-on" which enhances incineration destruction by injecting oxygen into the combustion train, thereby increasing throughput. <u>Conventional comparison:</u> Since PYRETRON® is an incineration "add-on," comparison with a conventional process is not applicable	Limiting factors include: • Supplied oxygen • Water These are probably limiting factors only for transportable incinerators.	PYRETRON® system can be less costly than conventional systems, especially when treating waste with low heating value, when auxiliary fuel and operating costs are relatively high, and when oxygen costs are relatively low. Cost savings based on the demo, are about $45/ton. <u>Conventional comparison:</u> This is a specialty application item. Cost comparisons to conventional equipment would be based on specific applications.
Babcock & Wilcox (B&W) Cyclone Furnace Vitrification (CFV)	CFV can be used to treat soils, sludges, liquids and slurries contaminated with inorganics, organics and low level radioactive solid waste or mixed waste <u>Conventional comparison:</u> Most conventional incineration units are not capable of burning mixed matrix streams without modifications. Incineration ash from conventional incineration technologies is considered a hazardous waste.	Limiting factors include: • Electrical source • Need for natural gas • Continuous water source • Site specific air and water permits • Moisture content • Storage/disposal facilities for water and slag • Downtime needed for maintenance • Feed rate • Particle size of feed	Cost range: $465 per ton (operating factor of 80%) $529 per ton (operating factor of 60%) Treating 20,000 tons of soil using the commercial cyclone furnace system, with a capacity of 3.3 tons per hour. <u>Conventional comparison:</u> Conventional incineration costs range from $800 - $1100 per ton for bulk soils. Liquids and slurries will start at $0.18 per pound and will increase inversely with the BTU value. Costs include transportation and disposal of residual ash. The CFV process has more limiting factors than conventional incineration.

Source: U.S. Environmental Protection Agency (EPA). 1989a. American Combustion, Inc. PYRETRON® Destruction System. Applications Analysis Report. Office of Research and Development. June.
EPA. 1992a. Babcock & Wilcox. Cyclone Furnace Vitrification Technology. Applications Analysis Report. Office of Research and Development. August.

TABLE 3-2 (Continued)

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY THERMAL DESTRUCTION

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
Horsehead Resource Development Flame Slagging Reactor (FSR)	The FSR is a high temperature metals recovery process that produces potentially recyclable metal oxide product and slag meeting RCRA TCLP standards. Conventional comparison: Metals shorten the life of kiln refractory in conventional incineration. Ash from conventional incineration is considered hazardous waste.	Limiting factors include: • Variability in waste feed • Transportation of the FSR • Cannot accept mercury contaminated wastes • Transportation, shipping, and handling of residuals	Cost per ton for treating secondary lead smelter waste: $932 Conventional comparison: Incineration cost for bulk solids will range from $800 - $1100 per ton which includes the cost for disposal of residual ash and landfill fees. The FSR costs do not include transportation and disposal of treated residues.
Retech, Inc. Plasma Centrifugal Furnace (PCF)	PCF uses heat generated from a plasma torch to treat organic and inorganic wastes. Metal bearing solids are melted and organic contaminants are thermally destroyed. Molten soil forms a hard glass-like nonleachable mass on cooling. Conventional comparison: Conventional incineration would be used to treat this waste and the resultant ash is considered a hazardous waste.	Limiting factors include: • Utility requirements • Cooling water (350 gallons per minute) • Capital costs of equipment • System must be erected in enclosed facility	Cost range: $1,816 per ton at a rate of 500 pounds/hour (lbs/hr) and operating factor of 70% $757 per ton at a rate of 2,200 lbs/hr and operating factor of 70% Conventional comparison: Incineration cost for bulk solids will range from $800 - $1100 per ton which includes the cost for disposal of residual ash and landfill taxes. The PCF costs do not include transportation and disposal of treated residues.

Source: U.S. Environmental Protection Agency (EPA). 1992e. Horsehead Resource Development Company, Inc. Flame Reactor Technology. Applications Analysis Report. Office of Research and Development. May.
EPA. 1992f. Retech, Inc. Plasma Centrifugal Furnace. Applications Analysis Report. Office of Research and Development. June.

TABLE 3-2 (Continued)

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY THERMAL DESTRUCTION

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
Gruppo Italimpresse Shirco Infrared Incineration (SII)	Shirco system can process solid waste or semi-solid, oily sludges with minimum particle size of 5 microns to 2 inches in diameter. <u>Conventional comparison:</u> The Shirco system can take a wider range of solid waste and oily sludges containing PCBs. Conventional incinerators must have special permits to burn PCB material. Ash from conventional incinerators is considered a hazardous waste.	Limiting factors include: • Powerful electric source • Natural gas • Continuous water source • Site-specific air and water permits • Moisture content and particle size of the feed • Suitable storage and disposal facilities for wastewater and ash • Downtime needed for maintenance • Feed rate • Presently unavailable in U.S.	Cost range per cubic yard: $182 to $241 Based on an operating time of 50-75% <u>Conventional comparison:</u> Conventional incineration of PCB contaminated sludges cost from $0.60 - $1.40 per pound. A high BTU value of the sludge will lower the cost. This includes disposal of any residual ash. The SII costs do not include transportation and disposal of treated residues.

Source: U.S. Environmental Protection Agency (EPA). 1989c. Shirco Infrared Systems, Inc.. Shirco Infrared Incineration System. Applications Analysis Report. Office of Research and Development. June.

4.0 THERMAL DESORPTION

Thermal desorption processes involve heating soil contaminated with volatile organic compounds VOC and SVOCs, to volatilize the contaminants. Heating is accomplished in a direct or indirectly heated reactor. The contaminants are then removed from an off-gas stream. The desorbed organic contaminants can be recovered and handled separately, destroyed in an afterburner, or destroyed via thermal or catalytic oxidation.

Thermal desorption provides an alternative to thermal destruction and differs from thermal destruction in several ways. First, treatment temperatures for desorption systems are below the temperatures typically used for thermal destruction. Thermal desorption requires heating contaminated soil to 200 to 500 °C instead of the 1,000 to 1,200 °C normally associated with thermal destruction. Second, the thermal desorption process removes rather than destroys volatile organic contaminants. Third, treated soil is not transformed to ash, thus providing a potentially more desirable fill material. Finally, thermal desorption systems generally do not have a problem with transformation by-products, such as dioxins, and with products of incomplete combustion.

In thermal desorption systems, contaminated soils and clean gas are fed to the desorption unit. Typically, the desorption unit consists of a rotary dryer or heated screw conveyor. Both direct and indirectly heated systems are available. Sweep gases that remove contaminants from the soil are captured and treated. Gas treatment systems vary among thermal desorption systems based on type of sweep gas (typically air or nitrogen), type of contaminants, and degree of potential product recovery. Additional information on thermal desorption technologies is found in EPA's Engineering Bulletin EPA/540/5-94/501.

4.1 EVALUATION OF SITE TECHNOLOGY DEMONSTRATIONS

The SITE demonstrations provide evidence that thermal desorption is a viable, cost effective alternative to thermal destruction. SITE demonstrations also provide evidence of the technology's ability to remove contaminants from soils, sediments, and sludges contaminated with a wide variety of organic contaminants, while having low air emissions. These organic contaminants include the following: VOCs, SVOCs, including PCBs, and some PAHs. Thermal desorption has proven most effective at treating VOCs.

Four thermal desorption innovative treatment technologies have been demonstrated in the SITE Program. A summary of the SITE demonstration technologies is provided in Table 4-1, and a summary of the technology applications and cost information is provided in Table 4-2. Both tables follow this section. Information regarding the results or accomplishments of each SITE demonstration is summarized below.

Canonie Environmental Services Corporation (Canonie) developed the Low Temperature Thermal Aeration (LTTA®) technology. LTTA is a low-temperature desorption process. It removes organic contaminants from contaminated soils into a contained air stream, which is extensively treated to either collect the contaminants or thermally destroy them. LTTA was evaluated through a SITE demonstration at an abandoned pesticide mixing facility in central Arizona in September 1992.

SoilTech ATP Systems, Inc. (SoilTech), developed the Anaerobic Thermal Processor (ATP). Contaminated soils, sludges, and liquids are heated and mixed in a special, rotary in directly-fired rotary kiln. The unit desorbs, collects, and recondenses hydrocarbons and other pollutants found in contaminated materials. The ATP was evaluated through two SITE demonstrations at (1) the

Wide Beach Development (WBD) site in Brant, New York, in May 1991 and (2) the Outboard Marine Corporation (OMC) Superfund site in Waukegan, Illinois,in June 1992.

Roy F. Weston, Inc. (Weston), developed the Low Temperature Thermal Treatment (LT^3®) system, which thermally desorbs organic compounds from contaminated soil without heating the soil to combustion temperatures.

LT^3® was evaluated in a SITE demonstration in November and December 1991, at the Anderson Development company (ADC) Superfund site in Adrian, Michigan.

Chemical Waste Management, Inc. (CWM), developed the X*TRAX™ Model 200 Thermal Desorption System (X*TRAX™), which removes organic contaminants as a condensed liquid, characterized by a high heat rating, which may then be either destroyed in a permitted incinerator or used as a supplemental fuel. Because of low operating temperatures (200 to 900 degrees Fahrenheit) and gas flow rates, this process is less expensive than incinerators. X*TRAX™ was demonstrated at the Re-Solve Superfund site in North Dartmouth, Massachusetts, in May 1992.

4.2 THERMAL DESORPTION TECHNOLOGY ADVANCEMENTS

The SITE demonstrations in this treatment have established thermal desorption as a viable technology for treating both volatile and semi-volatile organic compounds, including PCBs, PAHs, and pesticides. Concerns regarding dioxin and furan formation have been addressed. Results indicate that formation of these compounds can be controlled through proper waste characterization pretreatment, and process operation. A significant advancement that SITE has proven to be successful, is the combination of thermal desorption with chemical dechlorination technologies.

TABLE 4-1

SITE DEMONSTRATION TECHNOLOGIES SUMMARY THERMAL DESORPTION

DEVELOPER/TECHNOLOGY/AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS	DEMONSTRATION RESULTS	REMOVAL EFFICIENCIES
Canonie Environmental Services Corporation Low Temperature Thermal Treatment Aeration (LTTA®) Technology EPA AAR in preparation	September 1992 Abandoned pesticide mixing facility in central Arizona	1,180 tons of sandy soil with low moisture content Feed Soil (ppm) 4,4'-DDD1.89 4,4'-DDE 6.98 4,4'-DDT 18.70 Dieldrin 0.783 Endosulfan I 0.850 Endosulfan II 0.408 Endrin 0.526 Endrin Aldehyde 0.170 Toxaphene 21.70	Treated Soil (ppm) 4,4'-DDD0.0004 4,4'-DDE 0.683 4,4'-DDT 0.001 Dieldrin 0.0005 Endosulfan I 0.0004 Endosulfan II 0.001 Endrin 0.0004 Endrin Aldehyde 0.003 Toxaphene 0.020	Removal Efficiencies (RE) for Pesticides: Toxaphene and 4,4'-dichlorodiphenyl-dichloroethane (DDD) >99.99% 4,4'-dichlorodiphenyl-trichloroethane (DDT) 99.75 - > 99.99% 1,1-dichloro-2,2 bis(p-chlorophenol)ethylene (DDE) 82.37 - 97.75%
SoilTech ATP Systems, Inc. (SoilTech) Anaerobic Thermal Processor (ATP) EPA AAR in preparation	May 1991 Wide Beach Development (WBD) site, Brant, New York	104 tons of soil contaminated with PCBs Feed Soil (ppm) PCB 28.2	Treated Soil (ppm) PCB 0.043	Average RE for PCBs: 99.85% Stack Emissions: 23.1 micrograms of particulates per dry standard cubic meter (µg/dscm) Destruction Removal Efficiency (DRE) for Stack Gas: 99.807%
	June 1992 Outboard Marine Corporation (OMC) Waukegan Harbor Superfund site in Waukegan, Illinois	253 tons of soils and sediments, primarily harbor sand and sandy soil, contaminated with PCBs Feed Soil (ppm) PCB 9,761	Treated Soil (ppm) PCB 2	Average RE for PCBs: 99.98% Stack Emissions: 0.837 milligrams of particulates/dscm DRE for Stack Gas: 99.999988%

Source: EPA 1993b. Canonie Environmental Services Corporation. Low Temperature Thermal Treatment Aeration (LTTA®) Technology. Draft Applications Analysis Report. Office of Research and Development. January.
EPA 1993k. Soiltech ATP Systems, Inc. Anaerobic Thermal Processor. Draft Applications Analysis Report. Office of Research and Development. March.

TABLE 4-1 (Continued)

SITE DEMONSTRATION TECHNOLOGIES SUMMARY THERMAL DESORPTION

DEVELOPER/TECHNOLOGY/AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS	DEMONSTRATION RESULTS	REMOVAL EFFICIENCIES
Roy F. Weston, Inc. (Weston) Low Temperature Thermal Treatment (LT^3) System EPA AAR in preparation	November-December 1991 Anderson Development Company (ADC) Superfund site in Adrian, Michigan	80 tons of chemical treatment sludge, dewatered by filter press with addition of lime and ferric chloride Feed Soil (ppm) Toluene 1,000 - 25,000 PCE 690 - 1,900 4,4'-Methylenbis (2-chloroaniline) (MBOCA) 43.6 - 860 Methyl phenol 3,100 - 20,000 Bis(2-ethylhexyl) phthalate 1,100 - 7,900 1,2-Dichloro benzene 1,400 - 110,000 Phenol 470 - 4,200	Treated Soil (ppm) Toluene <0.03 PCE <0.03 4,4'-Methylenbis (2-chloroaniline) (MBOCA) 3 - 9.6 Methyl phenol 0.54 - 4 Bix(2-ethylhexyl) phthalate <0.82 1,2-Dichloro benzene <0.82 Phenol 1.3 - 7.8	RE for VOCs: 96 to > 99% RE for SVOCs: 57 to 99% RE for MBOCA: 79.8 to 99.3% Phenol concentration increased due to chemical transformation of 1,2-dichlorobenzene. Also, under certain combustion conditions the by-products dibenzo(p)dioxins and polychlorinated dibenzofurans can be found.
Chemical Waste Management, Inc. X*TRAX™ Model 200 Thermal Desorption System (X*TRAX™) EPA AAR in preparation	May 1992 Re-Solve Superfund Site in North Dartmouth, Massachusetts	215 tons of granular and sandy soils and sediment contaminated with PCBs. Feed Soil (ppm) PCB 247	Treated Soil (ppm) PCB 0.13	RE for PCBs: 99.95%
In-Situ Steam/Hot Air Stripping Technology (In-Situ Stripper) EPA/540/A5-90/008	May 1992 GATX Annex Terminal site in San Pedro, California	65 yd^3 of material was treated. Feed Soil (ppm) VOC 473 SVOC 902	Treated Soil (ppm) VOC 71 SVOC 409	RE for VOCs: 85% RE for SVOCs: 55%

Source: U.S. Environmental Protection Agency (EPA). 1992i. Roy F. Weston, Inc. Low Temperature Thermal Treatment ($LT^{3®}$) System. Draft Applications Analysis Report. Office of Research and Development. December.
U.S. Environmental Protection Agency (EPA). 1993d. Chemical Waste Management, Inc. X*TRAX™ Model 200 Thermal Desorption System. Draft Applications Analysis Report. Office of Research and Development. September.

TABLE 4-2

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY THERMAL DESORPTION

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL	
Canonie Environmental Services Corporation Low Thermal Treatment Aeration (LTTA)	LTTA is designed to desorb hazardous organic constituents at low temperatures (300°F to 800°F), into an enclosed air stream. LTTA has a rotary drum designed for high throughput rates. LTTA has achieved pesticide removal efficiencies ranging from 82.4 to greater than 99.9 percent. Conventional comparison: Conventional incineration: • More costly than LTTA • Produces potentially hazardous ash • Lower throughput rate	Limiting factors include: • Utility costs • Carbon replacement and disposal • Wastewater discharge • Treated soil disposal Feed material should be: • Less than 2 inches • Less than 20 percent moisture	Cost per ton: $207 $144 $133 Based on the cost to process 10,000 tons of soil Conventional comparison: Cost of conventional incineration will range from $800 to $1100 per ton which includes the transportation and disposal of any hazardous residual ash.	Average processing Rate (tons/hour): 20 35 50
SoilTech ATP Systems, Inc. Anaerobic Thermal Processor (ATP)	Thermally desorbs and removes PCBs and other organic contaminants from soil and sediment. Designed for high throughput rates and well suited for oily wastes. High potential for ATP as treatment technology for PCBs or other chlorinated organics. Conventional comparison: Conventional incinerators require special permits for the destruction of PCBs. As a specialized technology, ATP may qualify for a technology permit to destroy PCBs, therefore making it amenable to a transportable incineration application.	Limiting factors include: • Electricity • Need for natural gas or equivalent • Cooling and fire water • Compressed Nitrogen • Moisture content of feed should be less than 20 percent.	Cost range: $155 to $265 per ton (excluding fixed costs) $264 to $298 per ton (including fixed costs) Conventional comparison: Costs of conventional incineration of PCB contaminated soils or other solids range from $1200 to $2800 per ton which includes transportation and disposal of any residual hazardous ash.	

Source: U.S. Environmental Protection Agency (EPA). 1993c. Canonie Environmental Services Corporation. Low Temperature Thermal Treatment Aeration (LTTA®) Technology. Draft Applications Analysis Report. Office of Research and Development. January.
EPA. 1993. SoilTech ATP Systems, Inc. Anaerobic Thermal Processor. Draft Applications Analysis Report. Office of Research and Development. March.

TABLE 4-2 (Continued)

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY THERMAL DESORPTION

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
Roy F. Weston LT^3 System	The LT^3 System has thermal screw conveyors with circulating heating oil designed to treat sludges and soils with a widely varying moisture content. The Applications Analysis Report has shown that the system can remove most volatile organic compounds to below 60 micrograms per kilogram (µg/kg). <u>Conventional comparison</u>: Since LT^3 is a nondestructive thermal desorption technique no direct comparison exist to conventional thermal destruction.	Limiting factors include: • Dust handling • Off-site disposal of desorbed organics • Carbon replacement and disposal • Off-site soil disposal (if necessary) Feed material with soil moisture contents greater than 75 percent may require dewatering prior to treatment.	Cost per ton: / Percent moisture content: $373 / 20 $537 / 45 $725 / 75 Process Rate: 2.1 tons per hour <u>Conventional comparison</u>: Costs for conventional incineration range from $800 to $1100 per ton and includes the cost of transportation and disposal of residual hazardous residue. The LT^3 System costs do not include transportation and disposal of treated residues.
Chemical Waste Management X*TRAX	The X*TRAX System processes a wide variety of solids with moisture content of less than 50 percent. <u>Conventional comparison</u>: Since X*TRAX is a nondestructive thermal desorption technique no direct comparison can be made with conventional thermal destruction.	Limiting factors include: • Feed size less than 1.0 inch • Soil feed rate • High maintenance • Limited contaminant application • May require regulatory permit • Treated material may require further treatment • Soil moisture content • Off-site disposal of desorbed contaminants	Cost range: $281 per ton (based on 10,000 tons) $166 per ton (based on 35,000 tons) $137 per ton (based on 100,000 tons) Process Rate: 4.9 tons per hr <u>Conventional comparison</u>: Costs for conventional incineration range from $800 to $1100 per ton and includes transportation and disposal of residual hazardous residue. The X*TRAX™ costs do not include transportation and disposal of treated residues.

Source: U.S. Environmental Protection Agency (EPA). 1992h. Roy F. Weston, Inc. Low Temperature Thermal Treatment ($LT^{3®}$) System. Draft Applications Analysis Report. Office of Research and Development. December.
EPA. 1993e. Chemical Waste Management, Inc. X*TRAX™ Model 200 Thermal Desorption System. Draft Applications Analysis Report. Office of Research and Development. September.

5.0 SOLIDIFICATION/STABILIZATION

Solidification/stabilization (S/S) treatment technologies have been used to chemically fix and immobilize heavy metals and organic compounds in contaminated matrices. These technologies (1) reduce transfer or loss of hazardous constituents, (2) improve the handling characteristics of a waste and (3) reduce the cost of treatment and disposal by providing on-site treatment and disposal. EPA Superfund guidelines place S/S technologies in the broader immobilization technology category.

Under the SITE Program, solidification is defined as the process that converts contaminated soil, solid, sludge and liquid waste into easily handled waste materials for disposal. S/S treatment technologies can be used following biological, physical/chemical, and thermal treatment to further immobilize wastes. Additional information on S/S treatment technologies is found in EPA's Engineering Bulletin number EPA/540/S-92/015.

5.1 EVALUATION OF SITE TECHNOLOGY DEMONSTRATIONS

Five S/S innovative treatment technologies have been demonstrated under the SITE Program. Demonstrations have indicated that S/S is a potentially viable, cost effective alternative to more expensive technologies such as incineration. SITE demonstrations have provided evidence of the technology's ability to immobilize contaminants, especially metals, from soils, sediments, and sludges while avoiding large-scale excavation and treatment. Both tables follow this section. Table 5-1 summarizes the completed SITE demonstrations, and Table 5-2 summarizes the SITE demonstration costs and S/S technology information.

Chemfix Technologies, Inc. (Chemfix) developed the Chemfix Process®, which was demonstrated in March 1989, at the Portable Equipment Salvage Company site in Clackamas County, Oregon. The Chemfix Process® uses pozzolanic materials, which react with polyvalent metal ions and other waste components to produce a chemically and physically stable solid material.

Funderburk and Associates, Inc. (Formerly Em Tech, Inc. and Hazcon, Inc.) developed the former HAZCON immobilization process, which was demonstrated in October 1987, at the Douglasville Disposal, Inc. Superfund site at Douglasville, Pennsylvania. The former HAZCON process, now the Funderburk process, uses cement, water, and one of 18 patented immobilization reagents commonly known as "Chloranan" to immobilize and stabilize heavy metals and organic contaminants in hazardous wastes.

IWT and Geo-Con, Inc. (IWT/Geo-Con) are separate companies that affiliated for this SITE demonstration. IWT/Geo-Con developed this in situ S/S process, which was demonstrated in April 1988 at General Electric Company's electric service shop in Hialeah, Florida. IWT/Geo-Con's S/S process immobilizes organic and inorganic contaminants in wet or dry soil using reagents and additives to produce a cement-like mass.

Silicate Technology Corporation (STC) developed the SOILSORB S/S treatment reagents, which was demonstrated in November 1990 at the Selma Pressure Treating site in Selma, California. The SOILSORB HC process for treatment of organic compounds oxidizes or dechlorinates selected organic contaminants by more than 95 percent. The SOILSORB HM process chemically fixates/stabilizes inorganic contaminants by forming insoluble chemical compounds, thus reducing the leachability of inorganic contaminated soils and sludges. Both SOILSORB processes can be combined to treat and immobilize wastes which contain both inorganic and organic contaminants.

Soliditech, Inc. developed the Urrichem S/S process, which was demonstrated in December 1988 at Imperial Oil Company/Champion Chemical Company Superfund site in Morganville, New Jersey. The Soliditech process uses Urrichem, a proprietary reagent, water, proprietary additives, and pozzolanic materials, which are blended in a mixer and then are solidified forming a concrete-like, leach-resistant matrix.

5.2 SOLIDIFICATION/STABILIZATION TECHNOLOGY ADVANCEMENTS

Over the last five years, a variety of proprietary S/S additives and reagents have been demonstrated under the SITE Program. By demonstrating S/S additives and reagents, EPA has developed data to (1) provide guidelines on the cost effectiveness of treatment technologies comparing conventional versus innovative S/S technologies, (2) evaluate the performance of various fixative materials available for treatment, (3) address the potential physical handling problems and techniques of using S/S technologies, (4) address the long-term stability and effectiveness of S/S on inorganic and organic contaminated wastes, and (5) demonstrate that S/S treatment technologies are cost effective when treating inorganic contaminated wastes.

A related advancement in S/S technology is the development of various analytical procedures for solidified wastes. SITE evaluations generally require feasibility studies, bench-scale screening, and pilot-scale demonstrations to evaluate the performance of individual S/S technologies. These evaluations have assisted with the development of the following EPA protocol documents:

- *Stabilization/Solidification of CERCLA and RCRA Wastes. Physical Tests, Chemical Testing Procedures, Technology Screening, and Field Activities* (EPA 1989)

- *Technical Resource Document, Solidification/Stabilization and its Application to Waste Materials* (EPA 1993)

TABLE 5-1
SITE DEMONSTRATION TECHNOLOGIES SUMMARY
SOLIDIFICATION/STABILIZATION

DEVELOPER/ TECHNOLOGY/ AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS	DEMONSTRATION RESULTS	REMOVAL EFFICIENCIES
Chemfix Technologies, Inc. (Chemfix) Chemfix Process® uses CHEMSET® C-220 family of polysilicates and CHEMSET® family of dry calcium-containing reagents EPA/540/A5-89/011	March 1989 Portable Equipment Salvage Company site, Clackamas County, Oregon	<u>Feed Soil (ppm)</u> Copper 18,000 to 74,000 Lead 11,000 to 140,000 Zinc 1,800 to 8,000 Copper [TCLP] 12 to 120 Lead [TCLP] 390 to 880 Zinc [TCLP] 16 to 71 Unspecified soils and sludges with about 30 percent moisture and less than 30 percent organic content	<u>Treated Soil (ppm)</u> Copper 18,000 to 74,000 Lead 11,000 to 140,000 Zinc 1,800 to 8,000 Copper [TCLP] 12 to 120 Lead [TCLP] 390 to 880 Zinc [TCLP] 16 to 71 The Chemfix Process did not reduce or effectively treat VOCs, SVOCs, oil and grease, or PCBs. Unconfined compressive strength (UCS) results exceeded EPA solidification guidelines of 50 (psi). Permeability was not conducted during this demonstration. Wet/dry and freeze/thaw weathering tests: Less than one percent weight loss Waste volume: Increased by 20 to 50 percent with the addition of Chemfix reagents	Removal efficiencies were not determined for this demonstration.
Funderburk and Associates (Formerly Em Tech, Inc., and Hazcon, Inc. HAZCON process using Chloranan and other pozzolanic materials EPA/540/A5-89/001	October 1987 Douglasville Disposal, Inc. Superfund site at Douglasville, Pennsylvania	Sandy, clay and loam soils containing 1 to 25 percent oil and grease, 0.3 to 2.3 percent heavy metals (primarily lead), and greater than 500 ppm SVOCs <u>Feed Soil (ppm)</u> LGN / FCS / LF / PFA / LGS Chromium 19 / 31 / 46 / 95 / 750 Lead 9250 / 22,600 / 13,670 / 7,930 / 14,830 ~~Zinc 150 / 655 / 735 / 1,600 / 5,800~~ Chromium [TCLP] <0.008 / 0.270 / <0.008 / <0.008 / <0.008 Lead [TCLP] 31.8 / 17.9 / 27.7 / 22.4 / 52.6 Zinc [TCLP] 1.1 / 23.0 / 6.7 / 1.4 / 4.8 LGN = Lagoon North, FCS = Filter Cake Sludge Area, LF = Landfarm area, PFA = Processing Facility Area, LGS = Lagoon South	<u>Treated Soil (ppm)</u> LGN / FCS / LF / PFA / LGS Chromium NR / NR / NR / NR / NR Lead 2,800 / 10,300 / 1,860 / 3,280 / 3,200 ~~Zinc NR / NR / NR / NR / NR~~ Chromium [TCLP] <0.007 / 0.020 / <0.007 / <0.007 / <0.008 Lead [TCLP] <0.002 / 0.07 / 0.04 / 0.01 / 0.14 Zinc [TCLP] <0.02 / 0.02 / 0.04 / 0.02 / 0.04 VOCs and PAHs were not effectively immobilized. UCSs of the treated waste ranged from 220 psi for the FCS and 1,750 psi for the PFA. All UCS results met EPA solidification guidance of 50 psi. Weathering tests were satisfactory. The 28 day permeability test had results which ranged from 8.4 x 10^{-8} to 5.0 x 10^{-9} centimeters/second.	Removal efficiencies were not determined for this demonstration.

Source: U.S. Environmental Protection Agency (EPA). 1991c. Chemfix Technologies, Inc. Solidification/Stabilization Process. Applications Analysis Report. Office of Research and Development. May.
U.S. Environmental Protection Agency (EPA). 1989b. Hazcon, Inc. HAZCON Solidification Process, Douglasville, Pennsylvania. Applications Analysis Report. Office of Research and Development. May.

TABLE 5-1 (Continued)

SITE DEMONSTRATION TECHNOLOGIES SUMMARY SOLIDIFICATION/STABILIZATION

DEVELOPER/ TECHNOLOGY/ AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS	DEMONSTRATION RESULTS	REMOVAL EFFICIENCIES
International Waste Technologies Corp. (IWT)/Geo-Con, Inc. (Geo-Con) IWT's HWT-20 chemical was used in the S/S process EPA/540/A5-89/004	April 1988 General Electric Company electric service shop in Hialeah, Florida	Sandy soil containing porous coral-like limestone <u>Feed Soil (ppm)</u> PCB <1 - 650 Copper 59 - 910 Lead 280 - 2,500 Zinc 190 - 1,000 VOCs 189 - 1,485 PCB [TCLP] <0.0001 - 0.4 Copper [TCLP] 0.02 - 0.24 Lead [TCLP] 0.05 - 0.20 Zinc [TCLP] 0.29 - 2.2 VOCs [TCLP] 2.49 - 4.42	<u>Treated Soil (ppm)</u> PCB <1 - 170 Copper 6 - 39 Lead 11 - 140 Zinc 17 - 80 VOCs 24 - 41.3 PCB [TCLP] <0.2 - <1.0 Copper [TCLP] 0.04 - 0.06 Lead [TCLP] 0.03 - 0.1 Zinc [TCLP] 0.03 - 0.1 VOCs [TCLP] <0.013 - 0.604 Wet/dry weathering tests: Less than 0.5 percent weight loss. Freeze/thaw weathering tests: 3.0 and 30.7 percent weight loss. Waste volume: Increased by 8.5 percent with the addition of HWT-20. Permeability tests: Untreated soil 1.8 x 10^{-2} cm/sec; treated soil 4.2 x 10^{-7} cm/sec.	Percent Reduction PCB 0% to 30% Copper 0% to 75% Lead 0% to 65% Zinc 67% to 98% VOCs 87% to 99% PCBs appear to be immobilized; however the analytical results for untreated soil were low and close to PCB analytical detection limits. Immobilization of VOCs and SVOCs may occur; however insufficient data exist to confirm that immobilization will occur. UCS results ranged from 75 to 579 psi, which exceeds the EPA solidification guidelines of 50 psi.
Silicate Technology Corporation (STC) SOILSORB proprietary reagents (P-4 and P-27) used in S/S process EPA/540/AR-92/010	November 1990 Selma Pressure Treating Site in Selma, California	Coarse to very-fine, sandy soil containing oil and grease (up to 20,000 ppm) <u>Feed Soil (ppm)</u> PCP 2,000 to 8,300 Arsenic 270 to 2,200 Chromium 340 to 2,100 Copper 330 to 1,300 PCP [TCLP] 1.5 TO 2.3 Arsenic [TCLP] 1.1 to 3.3 Chromium [TCLP] <0.025 to 0.27 Copper [TCLP] 1.4 to 9.4	<u>Treated Soil (ppm)</u> PCP 80 to 170 Arsenic 200 to 1,600 Chromium 270 to 1,300 Copper 210 to 780 PCP [TCLP] <0.25 to 5.5 Arsenic [TCLP] 0.09 to 0.88 Chromium [TCLP] 0.19 to 0.32 Copper [TCLP] 0.06 to 0.10 Long-term results indicate that the 18-month cured samples showed improvement over the 6-month cured samples. UCS treated results ranged from 259 to 347 psi, which exceeded EPA solidifcation guidelines of 50 psi.	Percent Reduction Arsenic 35% to 92% Copper 90% to 99% PCP and chromium percent reductions were not determined. Wet/dry and freeze/thaw weathering tests: Less than 0.1 percent weight loss. Waste volume: Increased by 59 to 75 percent with the addition of SOILSORB. Permeability tests: untreated waste not tested; treated waste ranged from 0.8 x 10^{-7} cm/s.

Source: EPA 1990b. International Waste Technologies Corp./Geo-Con, Inc. In-Situ Stabilization/Solidification. Applications Analysis Report. Office of Research and Development. August.
EPA 1992g. Silicate Technology Corporation. Solidification/Stabilization Technology for Organic and Inorganic Contaminants in Soils. Applications Analysis Report. Office of Research and Development. December.

TABLE 5-1 (Continued)

SITE DEMONSTRATION TECHNOLOGIES SUMMARY
SOLIDIFICATION/STABILIZATION

DEVELOPER/ TECHNOLOGY/ AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENT	DEMONSTRATION RESULTS	REMOVAL EFFICIENCIES
Soliditech, Inc. Urrichem, Portland cement and proprietary additives EPA/540/A5-89/005	December 1988 Imperial Oil Company/ Champion Chemical Company Superfund Site in Morganville, New Jersey	Soil, waste filter cake material from a site waste pile, and oily sludge, contaminated with low levels of various heavy metals and oil and grease Feed Soil (ppm) (see below)	Treated Soil (ppm) (see below) Waste material containing up to 17 percent oil and grease and 58 percent water were successfully immobilized: VOCs and SVOCs were low or not detected in untreated soil samples. UCS of treated waste samples ranged from 390 to 860 psi which exceeds EPA solidification guidelines of 50 psi. Wet/dry and freeze/thaw weathering tests: Less than 1.0 percent weight loss Waste volume: Ranged from 0 to 59 percent increase with the addition of Urrichem Permeability tests: Untreated waste not tested; treated waste ranged from 4.5 x 10^{-7} to 8.9 x 10^{-9} cm/s	Percent Reduction Arsenic 60% to 90% Cadmium 0% to 4% Lead 95% to 99% Zinc 93% to 96%

Feed Soil (ppm)

	US	WFC	OS
Arsenic	94	26	14
Cadmium	1.5	0.37	1.0
Lead	650	2,200	2,500
Zinc	120	26	150
Arsenic [TCLP]	0.19	0.0050	0.014
Cadmium [TCLP]	<0.0050	0.0052	0.0043
Lead [TCLP]	0.46	4.3	5.4
Zinc [TCLP]	0.63	0.28	1.3

Treated Soil (ppm)

	US	WFC	OS
Arsenic	92	28	40
Cadmium	0.70	0.50	1.0
Lead	480	680	850
Zinc	95	23	54
Arsenic [TCLP]	0.017	<0.0020	<0.0020
Cadmium [TCLP]	<0.0050	<0.0050	<0.0050
Lead [TCLP]	<0.0050	<0.20	<0.050
Zinc [TCLP]	<0.02	<0.02	<0.02

Source: U.S. Environmental Protection Agency (EPA). 1990c. Soliditech, Inc. Solidification/Stabilization Process. Applications Analysis Report. Office of Research and Development. September.

TABLE 5-2

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY SOLIDIFICATION/STABILIZATION

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL	
Chemfix Technologies, Inc. Chemfix process	Solidification/stabilization (S/S) of heavy metals and organic contaminants in various types of soils, and inorganics and nonvolatile organic carbon in organic waste. <u>Conventional comparison:</u> Conventional stabilization agents such as cement kiln flue (CKF) dust are excellent for treatment of soils with metals and low organic content.	Limiting factors include: • Particle size less than 1 inch • Organic levels above 25% may interfere with the S/S process	Cost per cubic yard: $54 <u>Conventional comparison:</u> CKF costs $10 per ton of CKF plus the transportation cost. The amount of soil treated by CKF is dependent upon the organic and inorganic concentrations present. CKF is usually available within a 150 to 250 mile radius of most potential treatment sites and transportation costs will range from $18 - $20 per ton. A minimum tonnage charge is required for transportation. Not all CKF suppliers keep a large supply on hand.	Average processing Rate (cubic yards per day): 118

Source: U.S. Environmental Protection Agency (EPA). 1991c. Chemfix Technologies, Inc. Solidification/Stabilization Process. Applications Analysis Report. Office of Research and Development. May.

TABLE 5-2 (Continued)

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY SOLIDIFICATION/STABILIZATION

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
Funderburk & Associates (formerly Em Tech, Inc., and HAZCON, Inc.) HAZCON process	Designed to stabilize organic contaminants (oil, grease, and chlorinated organics) and heavy metals in solids and sludges. Process can also be applied to underwater sediments because the reagents are formulated to be hydrophobic. Conventional comparison: CKF dust is excellent for treatment of metals but the efficiency decreases as organic content increases. Since Hazcon process is hydrophobic it may have applications beyond conventional fixation agents.	Limiting factors include: • Low moisture material may require the addition of water, thus increasing the volume of S/S waste treated. • Cold weather (below 40 °F) may affect the hydration reactions, which can add significant amounts of time to a S/S project.	Cost range per cubic yard (yd^3): 1987: \$63 to \$137 Based on a total of 23,290 yds^3 treated with an average bulk density of 1.8 grams per cubic centimeter. 1993: \$200 Average ex situ S/S throughput is about 100 yds^3 per hour. Conventional comparison: CKF costs \$10 per ton of CKF plus the transportation cost. The amount of soil treated by CKF is dependent upon the organic and inorganic concentrations present. CKF is usually available within a 150 to 250 mile radius of most potential treatment sites and transportation costs will range from \$18 - \$20 per ton. A minimum tonnage charge is required for transportation. Not all CKF suppliers keep a large supply on hand.

Source: U.S. Environmental Protection Agency (EPA). 1989b. Hazcon, Inc. HAZCON Solidification Process, Douglasville, Pennsylvania. Applications Analysis Report. Office of Research and Development. May.

TABLE 5-2 (Continued)

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY SOLIDIFICATION/STABILIZATION

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL	
International Waste Technologies Corporation (IWT)/Geo-Con, Inc. (Geo-Con)	In Situ solidification/stabilization of heavy metals and organic contaminants in soil wastes and sludges. Product possibly combines physical/chemical immobilization with chemical destruction. <u>Conventional comparison:</u>	Limiting factors include: • Maximum depth of the auger is 150 feet below ground surface • Soil debris can hinder progress of auger • Slurry can freeze • Alignment of system hindered by uneven land contours or obstacles	Cost per cubic yard (yd^3): 1993: $41 Assume a 15% addition rate of 188 pounds of reagent per cubic yard of soil.	Processing rate (yds^3 per hour): Ex situ 40 - 225 In situ 100 - 140
IWT's HWT-20	CKF dust works best on stabilizing soils with metals, but decreases in efficiency as organic content increases. The heat of formation of CKF does not cause chemical destruction.		1988: $70 - $121 Total of 24,000 yds^3 treated; assumes waste has an average bulk density of 1.9 g/cm^3. <u>Conventional comparison:</u> CKF costs $10 per ton of CKF plus the transportation cost. The amount of soil treated by CKF is dependent upon the organic and inorganic concentrations present. CKF is available within a 150 to 250 mile radius of most potential treatment sites and transportation costs will range from $18 to $20 per ton. A minimum tonnage charge is required for transportation. Not all CKF suppliers keep a large supply on hand.	

Source: EPA. 1990b. International Waste Technologies Corp./Geo-Con, Inc. In Situ Stabilization/Solidification. Applications Analysis Report. Office of Research and Development. August.

TABLE 5-2 (Continued)

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY SOLIDIFICATION/STABILIZATION

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL	
			Cost range per cubic yard (yds^3)	Amount treated (yds^3)
Silicate Technology Corporation (STC) SOILSORB	Solidification/stabilization of organic and inorganic contaminants in various types of soils, wastes and sludges. Conventional comparison: CKF dust works best on stabilizing soils with metals, but decreases in efficiency as organic content increases.	Limiting factors include: • Not effective for wastewater contaminated with low molecular-weight organic contaminants (alcohols, ketones, and glycols). • Organic contaminant concentration	\$90 - \$330 Throughput of raw waste is based on two sizes of mixers (5 and 15 yds^3) and two different mixing times (0.5 hour(hr) and 1.0 hr). Using a 15-yd^3 mixer with a mixing time of 0.5 hr, the ex-situ S/S throughput rate was 1,200 yds^3 per week. Conventional comparison: CKF costs \$10 per ton of CKF plus the transportation cost. The amount of soil treated by CKF is dependent upon the organic and inorganic concentrations present. CKF is usually available within a 150 to 250 mile radius of most potential treatment sites and transportation costs will range from \$18 to \$20 per ton. A minimum tonnage charge is required for transportation. Not all CKF suppliers keep a large supply on hand.	15,000

Source: EPA. 1992g. Silicate Technology Corporation. Solidification/Stabilization Technology for Organic and Inorganic Contaminants in Soils. Applications Analysis Report. Office of Research and Development. December.

TABLE 5-2 (Continued)

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY SOLIDIFICATION/STABILIZATION

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
Soliditech, Inc. Urrichem Process	Solidification/stabilization of low level organics (below about 10 percent) and heavy metals in soils, wastes, and sludges. <u>Conventional comparison:</u> CKF is the standard treatment technology for metals. As organics increase the efficiency of CKF decreases.	Limiting factors include: • Water content may cause freezing in cold weather	Cost per cubic yard (yd^3): $152 Amount treated ($yds^3$): 5,000 The ex-situ throughput rate was about 400 yds^3/week, operating in a batch mode. <u>Conventional comparison:</u> CKF costs $10 per ton of CKF plus the transportation cost. The amount of soil treated by CKF is dependent upon the organic and inorganic concentrations present. CKF is usually available within a 150 to 250 mile radius of most potential treatment sites and transportation costs will range from $18 to $20 per ton. A minimum tonnage charge is required for transportation. Not all CKF suppliers keep a large supply on hand.

Source: EPA. 1990c. Soliditech, Inc. Solidification/Stabilization Process. Applications Analysis Report. Office of Research and Development. September.

6.0 BIOLOGICAL TREATMENT

Biological treatment employs the biodegradation capabilities of natural bacterial microorganisms to degrade and metabolize contaminants into non-hazardous constituents. Bioremediation approaches include both in situ and ex situ biodegradation processes. Biodegradation often requires inoculation of contaminated media to stimulate bacterial proliferation and mixing to improve waste-to-bacteria contact. Both aerobic and anaerobic bacteria are used, allowing treatment in both oxygenated and anoxic environments. Under the SITE Program, biological treatment has been applied to process sludges, contaminated soil, and contaminated water. Treatment has taken place in bioreactors as well as in native site conditions. Biodegradation is often an integral part of a treatment system which must address multiple contaminants and waste streams. The most frequently applied systems use soil washing followed by bioremediation.

6.1 EVALUATION OF SITE TECHNOLOGY DEMONSTRATIONS

Tables 6-1 and 6-2 summarize the five completed SITE bioremediation demonstrations. Both tables follow this section.

The BioGenesis™ Soil Washing Process showed effective integration of a biological treatment process with a soil washing technology to treat oil refinery wastes. A proprietary surfactant is used to wash oily wastes from soil. After washing, the oil can be reclaimed for reuse or disposal, and washwaters are treated in a bioreactor. Residual surfactant in the treated soil stimulates bioremediation of any remaining trace contaminants.

The demonstration of the BioTrol, Inc. Biological Aqueous Treatment System (BATS) was performed on groundwater contaminated with pentachlorophenol (PCP) from wood-preserving activities. The system utilizes immobilized bacterial populations in a submerged, multiple-cell, fixed-film reactor. Nutrient levels, temperature, oxygen, and other parameters are carefully controlled.

BioTrol, Inc. also demonstrated its integrated soil washing and bioremediation system for soils contaminated with PAHs and PCP. This system consists of debris separation, soil slurrying, a soil scrubbing unit with interstage size classification, biological treatment of the slurried fine-sized material, and biological treatment of washwaters in a fixed-film reactor.

ECOVA Corporation's Bioslurry Reactor was demonstrated on wood preserving wastes in soil and is also applicable to other wastes and to sludges and sediments. In this technology, the contaminated solids are slurried with water and transferred to batch and continuous-flow reactors. Specific bacterial inocula of indigenous or other naturally-occurring bacteria are added and nutrients, oxygen, and other parameters are carefully controlled.

6.2 BIOLOGICAL TREATMENT TECHNOLOGY ADVANCEMENTS

Advancements in the field of bioremediation have been substantial since the inception of the SITE Program. The Bioremediation Field Initiative, established by EPA to provide project managers and other remediation specialists with application data on biological methods, reports over 75 sites currently using biological methods to treat organic contamination.

Important advancements in this technology category have included:

- **Treatment of chlorinated aromatics and PCBs.** Bioremediation processes were originally used only to treat hydrocarbon contamination, such as petroleum wastes. In one of the first demonstrations of its kind, BioTrol demonstrated that PCP, a common contaminant, could be biologically degraded. Other projects are continuing to advance the state-of-the-art in this area.

- **Bioventing treatment.** Bioventing is a method in which air is injected into contaminated soil at rates low enough to increase oxygen concentrations and stimulate indigenous microbial activity without causing release of volatile emissions. The U.S. Air Force has announced a bioventing initiative, in which more than 55 sites are targeted for treatment by bioventing. Projects using bioventing or similar technologies are presently undergoing SITE Program demonstrations and evaluations.

- **In situ and on-site soil treatment.** Two SITE demonstrations involved in situ or on-site soil bioremediation. While not fully successful, both demonstrations illustrate the progress made in this area. Much work remains to optimize in situ bioremediation technologies and improve their reliability. Advancements in this area could bring about substantial cost savings in future soil remediation efforts.

TABLE 6-1

SITE DEMONSTRATION TECHNOLOGIES SUMMARY
BIOLOGICAL TREATMENT

DEVELOPER/TECHNOLOGY/AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS	DEMONSTRATION RESULTS	REMOVAL EFFICIENCIES
BioGenesis Enterprises, Inc. (BioGenesis) BioGenesis℠ Soil Washing and Biotreatment Process EPA/540/R-93/510	November 1992 Confidential Refinery Site	Oil sludges and soils contaminated with petroleum hydrocarbons Feed Soil (mg/kg) Run No.1 Run No.2 Run No.3 TRPH 7,600 7,567 9,933	Treated Soil (mg/kg) Run No.1 Run No.2 Run No.3 After Soil Washing TRPH 2,650 2,033 2,800 After 120-Day Biodegradation TRPH NA 980 1,000 Complete soil treatment incorporates a soil washing and a biodegradation reactor. Biodegradation treatment requires adequate storage space in a temperature moderated environment (above freezing) for a period of 120 days to 1 year depending upon target contamination level desired.	Removal Efficiencies by percent dry weight Run No.1 Run No.2 Run No.3 65% 73-83% 72-88%
BioTrol, Inc. BioTrol - Biological Aqueous Treatment System (BATS) EPA/540/A5-91/001	September 1989 MacGillis and Gibbs Co., New Brighton, Minnesota	Groundwater contaminated with wood preservative constituents Contaminated Groundwater (mg/L) Two groundwater feeds were tested: Pentachlorophenol (PCP) >50 and <50	Bioassay of the treated effluent indicated that acute lethality to minnows and water fleas was eliminated by the process.	Removal Efficiencies in groundwater Feed Conc. >50mg/L 99% Feed Conc. <50mg/L 95%

Source: EPA. 1993b. BioGenesis Enterprises, Inc. BioGenesis℠ Soil Washing Technology. Innovative Evaluation Report. Office of Research and Development. September
EPA. 1991b. Biotrol, Inc. Biological Aqueous Treatment. Applications Analysis Report. Office of Research and Development. September.

TABLE 6-1 (Continued)

SITE DEMONSTRATION TECHNOLOGIES SUMMARY
BIOLOGICAL TREATMENT

DEVELOPER/TECHNOLOGY/AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS	DEMONSTRATION RESULTS	REMOVAL EFFICIENCIES
BioTrol, Inc. BioTrol - Soil Washing System EPA/540/A5-91/003	September 1989 MacGillis and Gibbs Co., New Brighton, Minnesota	Soil contaminated with wood preservative constituents, PCP and PAH PCP Feed Soil (mg/kg) PCP 130-160 PAH Feed Soil (mg/kg) PAH 3.1 - 118.5	Bioassay of the treated soils by Microtox[SM] indicated that acute environmental toxicity characteristics were removed by the process. The soils washing process generates large solids, soil fines, and contaminated water effluents.	Removal Efficiencies by percent dry weight PCP Soil 87-89% PAH Soil 83-88%
ECOVA Corporation Bioslurry Reactor EPA/540/A-5/91/009	May - September 1991 EPA Testing Facility, Cincinnati, Ohio	Soil, sediments, and sludge contaminated with creosote and PAHs Feed Soil (mg/kg) PAH 5,081 ± 1,530	Treated Soil (mg/kg) - After 12 weeks PAH 501 ± 103 Data from the pilot-scale program will be used to establish treatment standards for K001 wastes as part of EPA's Best Demonstrated Available Technology (DBAT) program.	Removal Efficiencies After 1 week 82% ± 15% After 2 weeks 96% ± 2% After 12 weeks 97% ± 2% Total soil bound PAHs

Source: EPA. 1992b. BioTrol, Inc. Soil Washing System. Applications Analysis Report. Office of Research and Development. February.
EPA. 1993f. ECOVA Corporation. Bioslurry Reactor. Applications Analysis Report. Office of Research and Development.

TABLE 6-2

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY BIOLOGICAL TREATMENT

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
BioGenesis Enterprises, Inc. BioGenesis Soil Washing and Treatment Process	BioGenesis processes soils contaminated with petroleum hydrocarbons, chlorinated hydrocarbons, pesticides, PCB and PAH. <u>Conventional comparison:</u> Conventional treatment by incineration requires transportation and disposal of ash residue.	Limiting factors include: • Soil composition • Contaminant composition • Ambient temperature • Oxygen availability • Target cleanup level • Requires approximately 30,000 square feet for setup • Effluent may need to be treated • High metals content toxic to biodegradation organisms • Clay composition over 45% prevents contaminant removal	Cost range per cubic yard (yd^3): $94 - $367 Based on treating 150 to 1000 yd^3. <u>Conventional comparison:</u> Costs of conventional incineration of PCB contaminated soils will range from $1200 per ton ($0.60 per pound) to $2800 per ton ($1.40 per pound). Cost includes transportation and disposal of residual ash. BioGenesis may still require offsite transportation and disposal of treated residue.
BioTrol, Inc. BioTrol Biological Aqueous Treatment System (BATS)	Treats waters and sludges contaminated with VOCs and PCP. <u>Conventional comparison:</u> Waters may be treated by deep well injection. Sludges would be incinerated. At present only one incinerator is permitted to burn dioxins or dioxin precursors. It is not known how many deep well facilities can handle dioxins or their precursors.	Limiting factors include: • Contaminant composition • Ambient temperature • Oxygen availability • Target cleanup level	Cost for labor, chemicals, and utilities: $3.45 per 1,000 gallons at 5 gallons per minute (gpm) $2.43 per 1,000 gallons at 30 gpm Minimum Capital and Operating Costs: $2.93 per 1,000 gallons <u>Conventional comparison:</u> Costs to incinerate PCP contaminated sludges range from $8 to $25 per pound depending on the presence of additional organics and/or metals and additional handling requirements by the disposal facility. Costs do not include transportation. Deep well injection costs range from $0.18 to $0.25 per gallon for liquids with 0 to 0.5 percent total suspended solids (TSS). A surcharge of $0.12 to $0.16 per gallon will be assessed for each additional 0.5 percent TSS. There will be additional charges for handling out-of-phase organics.

Source: U.S. Environmental Protection Agency (EPA). 1993b. BioGenesis[SM] Soil Washing Technology. Innovative Evaluation Report. Office of Research and Development. September.
EPA. 1991b. Biotrol, Inc. Biological Aqueous Treatment. Applications Analysis Report. Office of Research and Development. October.

TABLE 6-2 (Continued)

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY BIOLOGICAL TREATMENT

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
BioTrol, Inc. BioTrol Soil Washing System	The BioTrol Soil Washing System processes soils contaminated with creosotes, phenols, and other PAHs. The system includes soil washing followed by biodegradation of contaminants in soil slurries and residual wash waters on-site. Conventional comparison: These soils would normally require conventional incineration.	Limiting factors include: • Soil composition • Contaminant composition • Ambient temperatures • Oxygen availability • Regulated target cleanup level	Cost per ton: \$168 Based on treating 30,000 yds^3 of pentachlorophenol PCP contaminated soil. Cost is \$40 per ton if incineration of fine and coarse oversized woody debris is excluded. Conventional Comparison: Cost to incinerate bulk soils range from \$800 to \$1100 per ton. This cost includes transportation and disposal of residual ash. As the BTU value increases, the cost usually decreases. If the soils contain PCPs the cost will range from \$8 to \$25 per pound and the incinerator must be permitted to handle the waste. The BioTrol process treated waste may still need to be incinerated to reduce the contaminant levels below acceptable EPA requirements.
ECOVA Corporation Bioslurry Reactor (BR)	The BR process treats primarily petroleum hydrocarbon and PAH contaminated soils, sediments and sludges. Conventional comparison: Conventional incineration is used to process these wastes. The BR treated soils may need further treatment to meet EPA requirements.	Limiting factors include: • Pilot-scale demonstration only • Soil composition • Contaminant composition • Ambient temperature • Oxygen availability • Target cleanup level • System configuration	Cost range per cubic yard: \$50 - \$250 Cost based on site specific requirements. Conventional comparison: Incineration of bulk soils costs from \$800 to \$1100 per ton. Sludges, which must be packaged in smaller containers, will cost \$0.40 - \$0.55 per pound. These costs include transportation and disposal of residual ash. If the waste contains dioxin precursors the cost will range from \$8 to \$25 per pound and the incineration site must be permitted.

Source: U.S. Environmental Protection Agency (EPA). 1992b. BioTrol, Inc. Soil Washing System. Applications Analysis Report. Office of Research and Development. February.
EPA. 1993f. ECOVA Corporation. Bioslurry Reactor. Draft Applications Analysis Report. Office of Research and Development. February.

7.0 PHYSICAL/CHEMICAL TREATMENT

Physical/chemical treatment is a broad technology category that encompasses a wide variety of processes. Physical treatment generally refers to methods that separate hazardous constituents without chemical transformation, while chemical treatment involves addition of outside agents, such as precipitating chemicals or oxidizers to effect a substantial change in the target compounds. Many technologies in the SITE Demonstration Program involve the simultaneous or sequential use of physical and chemical methods. For example, soil washing, advanced oxidation using ultraviolet (UV) light, soil vapor extraction (SVE), and solvent extraction technologies are included in this category. This technology category includes both in situ and ex situ treatment and incorporates technologies capable of treating soil, sediments, groundwater, and other contaminated aqueous streams.

Additional information on physical/chemical treatment technologies are found in EPA's Engineering Bulletin numbers EPA/540/2-90/013, EPA/540/2-90/015, EPA/540/2-90/017, EPA/540/2-91/005, EPA/540/2-91/006, EPA/540/2-91/021, EPA/540-2-91/025 and EPA/540/2-92/006.

7.1 EVALUATION OF SITE TECHNOLOGY DEMONSTRATIONS

A total of 14 physical/chemical treatment technologies have been demonstrated under the SITE Program. Table 7-1 summarizes important data from each demonstration. Table 7-2 summarizes the SITE demonstration costs and applications of physical/chemical treatment technologies. Both tables follow this section. Information pertaining to each demonstration technology is summarized below.

AWD Technologies, Inc. (AWD) developed the Integrated Aqua DeTox/Soil Vapor Extraction (SVE) System, which was demonstrated in September 1990, at Lockheed Aeronautical Systems Company in Burbank, California. The AWD Integrated AquaDetox/SVE System integrated two existing technologies in an innovative way: AquaDetox, a low-pressure steam stripping technology for the removal of VOCs from water, was combined with SVE to separate VOCs from soil gas. This system can simultaneously treat separate water and soil gas streams in a single closed-loop system. The demonstration met goals for reducing VOC levels to below regulatory discharge limits. The system was operated at the site for more than 2 years.

CF Systems Corporation (CF Systems) developed the Organics Extraction, which was demonstrated in September 1988, at New Bedford Harbor Superfund site in New Bedford, Massachusetts. The CF Systems Organics Extraction process used a pilot scale mobile treatment system on PCB-contaminated sediments. The technology uses liquified gases as solvents for removal of contaminants from solids or water. Solvents are recycled and contaminants are recovered for reuse or disposal. This technology was successfully demonstrated on PCB-laden sediments.

Dehydro-Tech Corporation (Dehydro-Tech) developed the Carver-Greenfield Process®, which was demonstrated in August 1991, at EPA's Office of Research and Development (ORD) facility in Edison, New Jersey. Dehydro-Tech's Carver-Greenfield Process was successfully tested at a pilot-scale (100 pounds per hour) on approximately 640 pounds of oily drilling mud wastes containing low concentrations of organics. This technology uses a food-grade solvent to separate hydrocarbon contaminants from sludges, soils, and industrial wastes. The solvent is recycled and contaminants are recovered for reuse or disposal.

Toxic Treatments, USA, Inc. (Toxic Treatments) developed the In Situ Steam/Hot Air Stripping Technology, which was demonstrated in the Fall 1989, at the GATX Annex Terminal site in the Port of Los Angeles, California. Toxic Treatments sold the company to NOVATERRA, Inc. in about 1990. The In Situ Steam/Hot Air Stripping Technology was tested successfully on soils contaminated with a wide range of VOCs and SVOCs including TCE, PCE, and chlorobenzene. This system mixes soil in situ using auger blades to enhance removal of contaminants via steam- and air-stripping. Terra Vac, Inc. (Terra Vac) developed the In Situ Vacuum Extraction System, which was demonstrated from December 1987 to April 1988, at the Valley Manufactured Product Company in Groveland, Massachusetts. The Terra Vac vacuum extraction technology was tested successfully on soils contaminated with VOCs including degreasing solvents (primarily TCE). This technology uses a vacuum pump to draw contaminants from the subsurface via a series of extraction wells. A liquid/gas separator and emissions control technologies are used to treat the extracted vapors.

Ultrox International, Inc. (Ultrox) developed the Ultraviolet (UV) Radiation/Oxidation Technology, which demonstrated from February to March 1989, at the Lorentz Barrel and Drum Company in San Jose, California. The Ultrox UV Radiation/Oxidation Technology was tested successfully on groundwater contaminated with TCE and vinyl chloride. This UV/oxidation technology subjects contaminated waters to UV radiation, ozone (O_3), and hydrogen peroxide (H_2O_2) simultaneously to oxidize contaminants. Air emissions controls include an ozone decomposition device.

E.I. DuPont De Nemours Company (E.I. DuPont) and Oberlin Filter Company (Oberlin Filter) codeveloped the Membrane Microfiltration Technology, which was demonstrated from April to May 1990, at the Palmerton Zinc site in Palmerton, Pennsylvania. E.I. DuPont's and Oberlin Filter's combined microfiltration technology was demonstrated on groundwater contaminated with zinc, cadmium, copper, lead, and selenium. This technology combines an automatic pressure filter mechanism developed by Oberlin with a Tyvek membrane microfilter material developed by E.I. DuPont.

EPOC Water, Inc. (EPOC) developed the Microfiltration Technology, which was demonstrated from May to June 1992, at the Iron Mountain Mine site in Redding, California. The EPOC microfiltration technology was tested on acid mine drainage containing approximately 3,000 mg/L total metals including iron, aluminum, arsenic, cadmium, copper, lead, magnesium, and zinc. The EPOC dynamic membrane microfiltration unit operates by passing water through a unique tubular cross flow microfilter (EXXFLOW). The concentrate stream is then dewatered in an automatic tubular filter press of the same material (EXXPRESS).

Toronto Harbor Commission (THC) developed the Soil Recycling Treatment Train, which was demonstrated in the fall 1992, at the Port of Toronto in Toronto, Ontario, Canada. The THC Soil Recycling Treatment Train consists of three soil remediation technologies: an attrition soil washer to segregate soil into uncontaminated coarse material and highly contaminated fines; a metals removal process based on chelation; and chemical and biological treatment for removal of organic contaminants. The process was tested on approximately 1,040 tons of soil contaminated with oil and grease and PAH compounds.

EPA RREL developed the Mobile Volume Reduction Unit (VRU), which was demonstrated in November 1992, at the Escambia Treating Company in Pensacola, Florida. The VRU developed by was tested on PCP- and PAH-contaminated soil. A surfactant, Tergitor, was used as the main agent for contaminant removal. This technology performs soil washing via subsystems including soil handling and conveying, soil washing, coarse screening, fine particle separation, flocculation/clarification, and water treatment.

Chemical Waste Management, Inc. developed the PO*WW*ER Technology, which was demonstrated in September 1992, at the CWM Lake Charles Treatment Center in Lake Charles, Louisiana. CWM's PO*WW*ER Technology was tested on landfill leachate contaminated with VOCs, SVOCs, ammonia, cyanide, metals, and other inorganic contaminants. The PO*WW*ER Technology combines evaporation of contaminants from wastewater with catalytic oxidation of the vapors. Air emissions controls in the form of a scrubber are sometimes required.

Resource Conservation Company developed the Basic Extractive Sludge Treatment (B.E.S.T.) Solvent Extraction System, which was demonstrated in July 1992, at the Grand Calumet River in Gary, Indiana. The

B.E.S.T. solvent extraction system was tested on sediments contaminated with PCBs and PAHs and is also applicable to sludge treatment. This technology consists of a mobile system including a cold extraction reactor, gravity and centrifuge solids separation, a heated reactor to separate water, steam stripping for solvent recovery from the water, and a solvent evaporator for contaminant separation. Solvent is recovered for reuse, and contaminants are reclaimed for reuse or disposal.

Peroxidation Systems, Inc. developed the UV Radiation and Hydrogen Peroxide Treatment (Perox-pure™ chemical oxidation) Technology, which was demonstrated in September 1992 at the Lawrence Livermore National

Laboratory Site 300 in Tracy, California. The perox-pure™ chemical oxidation technology system was tested on VOC-contaminated groundwater. The principal contaminants were TCE and PCE. This technology uses UV-oxidation combined with hydrogen peroxide to destroy organic contaminants in water.

SBP Technologies, Inc. (SBP) developed the Membrane Treatment Technology, which was demonstrated in October 1991, at the American Creosote Works in Pensacola, Florida. SBP's cross-flow membrane treatment system was tested on creosote-derived polynuclear aromatic hydrocarbon-(PAH) and pentachlorophenol- (PCP) contaminated groundwater at a wood treatment facility. This technology utilizes formed-in-place membranes in stainless steel support tubes and a cross-flow technique to separate a variety of contaminants from water. Membranes may be biodegradable to reduce disposal costs.

7.2 PHYSICAL/CHEMICAL TREATMENT TECHNOLOGY ADVANCEMENTS

The 14 completed demonstrations listed in this section use solvent extraction, stripping, microfiltration, oxidation, and other means to separate or destroy hazardous constituents. Although many physical and chemical technologies are still considered largely unproven, SVE is now considered to be an acceptable treatment technology, primarily due to its demonstration under the SITE Program. Similarly, UV oxidation is now considered to have a strong potential for wide application since its initial demonstration in 1989.

Important areas of achievement in this technology area are as follows:

Innovative applications of existing technologies to contaminated sites. The SITE Program has shown that technologies using extraction, a commonly employed method used by chemical industries, could be applied to contaminated solid media. The Carver-Greenfield Process, CF systems extraction, EPA's mobile volume reduction unit, and the B.E.S.T solvent extraction technology have all been shown to successfully remove contaminants from difficult matrices.

Introduction of microfiltration methods for removal small metallic and organic compounds from solution without incurring a large capital expenditure. The microfiltration technologies demonstrated have showed that toxic metals can be removed from contaminated water without the use of traditional wastewater treatment methods, such as clarification and settling. These technologies have provided a large potential for enhanced metals treatment at sites where conventional metals treatment would be inefficient. Similarly, SBP's cross-flow microfiltration technology demonstrated successful organics removal without typical, expensive fouling problems.

Substantial advancement of non-incineration destruction technologies. Oxidation technologies tested at SITE demonstrations have made a significant contribution to this area, proving that organic contaminants can be destroyed without resorting to expensive, large-scale technologies such as incineration. The Ultrox International (UV oxidation) demonstration has resulted in numerous developers providing improvements in this technology over the past several years. New developers have also extended other advanced oxidation methods to vapor phase destruction of organics, filling an important need in this area. This area is expected to experience continued growth through the decade.

TABLE 7-1

SITE DEMONSTRATION TECHNOLOGIES SUMMARY PHYSICAL/CHEMICAL TREATMENT

DEVELOPER/TECHNOLOGY/AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS	DEMONSTRATION RESULTS	REMOVAL EFFICIENCIES
AWD Technologies Integrated AquaDetox/SVE System EPA/540/A5-91/002	September 1990 Lockheed Aeronautical Systems Company, Burbank, California	Soil gas and groundwater VOCs, primarily trichloroethene (TCE) and tetrachloroethane (PCE) <u>Groundwater Contamination Levels</u> PCE Ranged from 2,000 to 2,500 (µg/L) TCE Ranged from 400 to 600 µg/L	Dependent upon the carbon regeneration frequency. Granular-activated carbon beds are effective at removing VOCs even after 24 hours of continuous operation without stream regeneration. Effective at removing VOCs with boiling points of 120°C and below. Expected to be effective at removing VOCs with boiling points up to 200°C.	Ranged from 99.92 to 99.99 percent removal efficiency (RE) for VOCs in groundwater. Ranged from 93 to 99.9 percent RE for VOCs found in soil gas vapors.
CF Systems Corporation Organics Extraction EPA/540/A5-90/002	September 1988 New Bedford Harbor Superfund Site, New Bedford, Massachusetts	Sediments Polychlorinated biphenyls (PCB) PCB sediment concentrations in the untreated waste were 350 and 2,575 ppm.	Operational control was difficult to maintain. Solvent flow fluctuated and solids were retained in process hardware, and were observed in organic extracts. The pilot-scale unit used in this demonstration required multiple treatment passes to simulate a full-scale, four-stage operational unit. PCB sediment concentrations in the treated waste were as low as 8 ppm.	PCB extraction efficiencies were greater than 90 percent.

Source: U.S. Environmental Protection Agency (EPA). 1991a. AWD Technologies. Integrated AquaDetox/SVE Technology. Applications Analysis Report. Office of Research and Development. October.
EPA. 1990a. CF Systems Corporation. Solvent Extraction. Applications Analysis Report. Office of Research and Development. August.

TABLE 7-1 (Continued)

SITE DEMONSTRATION TECHNOLOGIES SUMMARY
PHYSICAL/CHEMICAL TREATMENT

DEVELOPER/TECHNOLOGY/AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS	DEMONSTRATION RESULTS	REMOVAL EFFICIENCIES
Dehydro-Tech Corporation Carver-Greenfield Process® EPA/540/AR-92/002	August 1991 EPA ORD Edison, New Jersey	Waste oil production drilling muds, consisting of very fine clays, water and waste oils <u>Feed Waste Oil (mg/kg)</u> Test Run 1: VOCs 4.95 to 5.58 Test Run 2: VOCs >10.5 to 13.3	Total Toxicity Characteristic Leachate Procedure (TCLP) values for all tested metals and organic compounds in the treated soils were below RCRA regulatory limits. The final water discharged from this process may require further treatment depending on the metal and organics content and on local effluent discharge limitations.	Total VOCs were not analyzed on either test run. Over 90 percent of indigenous oil from the raw waste feedstock was removed. Essentially 100 percent of TPH was removed during both test runs.
NOVATERRA, Inc. (formerly Toxic Treatments, USA, Inc.) In Situ Steam/Hot Air Stripping Technology EPA/540/A5-90/008	Fall 1989 GATX Annex Terminal Site Port of Los Angeles, California	Clay soil <u>Pretreatment core samples (ppm)</u> VOCs 315 to 618 VOC Average 466 Semi VOCs 336 to 1403 Semi VOCs Average 902 <u>Posttreatment core samples (ppm)</u> VOCs 45 to 98 VOC Average 71 Semi-VOCs 49 to 818 Semi VOCs Average 409	Average electrical energy consumption was about 11 kilowatt-hours/operational hour. No evidence of fugitive VOC emissions during or after treatment. System operates in a batch-like mode, thus allowing control of VOC removal by varying the treatment time. VOC and SVOC testing indicates that the soil blocks have substantial heterogeneity between each one produced. Soils with a high clay content can be treated effectively, with longer treatment times required for sandy soils.	The average RE for total VOCs was 85 percent. The average RE for total semi VOCs was 55 percent.

Source: EPA. 1992c. Dehydro-Tech Corporation. Carver-Greenfield Process®. Applications Analysis Report. Office of Research and Development. August
EPA. 1991f. Toxic Treatments USA, Inc. In Situ Steam/Hot-Air Stripping Technology. Applications Analysis Report. Office of Research and Development. March.

TABLE 7-1 (Continued)

SITE DEMONSTRATION TECHNOLOGIES SUMMARY PHYSICAL/CHEMICAL TREATMENT

DEVELOPER/TECHNOLOGY/AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS	DEMONSTRATION RESULTS	REMOVAL EFFICIENCIES
Terra Vac, Inc. In Situ Vacuum Extraction System EPA/540/A5-89/003	December 1987-April 1988 Valley Manufactured Product Company Groveland, Massachusetts	Soil <u>Pretreated soils (mg/kg)</u> TCE 0.87 to 2.27 <u>Posttreated soils (mg/kg)</u> TCE 0.34 to 84.5 Permeabilities (centimeters per second)10^{-4} to 10^{-8}	VOC contaminated soils with wide ranging permeabilities can be removed using this process. Demonstration data indicates that less volatile hydrocarbons such as gasoline, diesel fuel, kerosene and heavy naphthas can also be removed from soils using this process. Organic vapor releases require carbon treatment before discharge. Total carbon usage was 15,200 pounds over a 56-day period. Total wastewater extracted over the same period was 17,000 gallons.	REs ranged from 0 to 95.6 percent.
Ultrox International Ultraviolet Radiation/Oxidation Technology EPA/540/A5-89/012	February-March 1989 Lorentz Barrel and Drum Company San Jose, California	Groundwater Organic compounds treated included TCE, vinylchloride, 1,1- and 1,2-dichloroethane (DCA) 1,1,1-trichloroethane (TCA), benzene, chloroform and PCE. <u>Feed groundwater (mg/L)</u> VOC 120-170 TCE 0.100 Vinyl chloride 0.040 Other VOCs 5-15 SVOCs and polychlorinated biphenyls/ pesticides were below detection limits.	About 13,000 gallons of groundwater was treated over 13 test runs. Operational problems include frequent UV lamp and ozone sparger cleaning, which are due to iron and manganese precipitation in the reactor. Proper pretreatment of metals will eliminate this problem. Ozone treatment unit destroyed ozone from off-gases from the reactor to less than 0.1 ppm.	REs for total VOCs ranged from 90 to 99.99 percent in most cases. The TCE RE was greater than 99 percent. The RE for 1,1- DCA and 1,1,1-TCA were less than 40 percent. Ozone RE was greater than 99.99 percent.

Source: EPA. 1989d. Terra Vac, Inc. In Situ Vacuum Extraction System. Applications Analysis Report. Office of Research and Development. July.
EPA. 1990d. Ultrox International. Ultraviolet Radiation/Oxidation Technology. Applications Analysis Report. Office of Research and Development. September.

TABLE 7-1 (Continued)

SITE DEMONSTRATION TECHNOLOGIES SUMMARY
PHYSICAL/CHEMICAL TREATMENT

DEVELOPER/TECHNOLOGY/AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS	DEMONSTRATION RESULTS	REMOVAL EFFICIENCIES
DuPont/Oberlin Filter Company Membrane Microfiltration Technology EPA/540/A5-90/007	April-May 1990 Palmerton Zinc site Palmerton, Pennsylvania	Groundwater contaminated by zinc plating operations Feed Groundwater (mg/L) Zinc 400-500 Cadmium 1 Lead 0.015 Selenium 0.05 pH 4.5 Alkalinity 15	The technology produced a filter cake with a solids content of 41 percent. The filter cake passed both toxicity characteristic leaching procedure and EP-toxicity tests. Filter cake passed the paint filter liquids test.	Zinc and total suspended solids (TSS) REs were about 99.95 percent. Treated effluent met the 95 percent confidence level for applicable National Pollutant Discharge Elimination System permit limits for metals and TSS. Treated effluent may require pH adjustment before discharge.
EPOC Water, Inc. Microfiltration Technology using EXXFLOW and EXXPRESS EPA AAR in preparation	May-June 1992 Iron Mountain Mine Site Redding, California	Groundwater, wastewater, acid mine drainage Feed Groundwater (mg/L) Total metals 3,000 Metal Precipitate (weight percentage) 1-2.5%	Dewatered sludge metals content ranged from 12 percent to greater than 30 percent by weight.	REs have not been determined for this treatment technology

Source: EPA. 1991d. E.I. DuPont De Nemours & Company/Oberlin Filter Company. Microfiltration Technology. Applications Analysis Report. Office of Research and Development. October.
EPA. 1993h. EPOC Water, Inc. Microfiltration Technology. Draft Applications Analysis Report. Office of Research and Development. May.

TABLE 7-1 (Continued)

SITE DEMONSTRATION TECHNOLOGIES SUMMARY PHYSICAL/CHEMICAL TREATMENT

DEVELOPER/TECHNOLOGY/AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS	DEMONSTRATION RESULTS	REMOVAL EFFICIENCIES
Toronto Harbour Commission (THC) Soil Recycling Treatment Train: soil attrition washing, metals removal, and bioslurry treatment EPA/540/AR-93/517	Fall 1992 Port of Toronto Toronto, Ontario, Canada	Soils, sediments Feed Soil (mg/kg) Oil and grease 8,200 TRPH 2,500 Copper 18.3 Lead 115 Zinc 83 Naphthalene 11.2 Benzo(a)pyrene 1.9	Organic and inorganic compounds can be removed from soil using these three treatment processes. The developer's primary claim that the sand and gravel component (representing 79.6 percent of the final product) meet THC's criteria levels for industrial soils. Fine slurry exhibited significant TRPH and polynuclear aromatic hydrocarbon reductions. The vendors results from other treatment studies indicate that the THC system can effectively remove metals. The system's hydroclone, designed to dry treatment residuals, did not sufficiently dewater treated soils.	Soil washing REs for gravel, sand and fine slurry were 67,78 and 74 percent, respectively, for oil and grease, TRPH, naphthalene and benzo(a)pyrene. The metals removal system was not tested during the demonstration because of the low levels of metals present in the feed soil. Bioslurry treatment Oil and grease RE was limited. REs on the fine slurry for other organic contaminants were: TRPH - 60 percent, naphthalene - at least 97 percent and benzo(a)pyrene - about 70 percent.

Source: EPA. 1993n. Toronto Harbour Commissioners. Soil Recycling Treatment Train. Draft Applications Analysis Report. Office of Research and Development. April.

TABLE 7-1 (Continued)

SITE DEMONSTRATION TECHNOLOGIES SUMMARY PHYSICAL/CHEMICAL TREATMENT

DEVELOPER/TECHNOLOGY/AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS	DEMONSTRATION RESULTS	REMOVAL EFFICIENCIES
EPA RREL Mobile Volume Reduction Unit (VRU) EPA/540/AR-93/508	November 1992 Escambia Treating Company, Pensacola, Florida	Soils <u>Feed Soil (ppm)</u> PAH range 550 - 1,700 average 980 PCP range 48 - 210 average 140 Three physical conditions were tested during the demonstration. These were as follows: Condition 1: no surfactant, no pH adjustment and no temperature adjustment Condition 2: surfactant addition, no pH adjustment and no temperature adjustment Condition 3: Surfactant addition, pH adjustment and temperature adjustment	High REs (greater than 90 percent) are more easily attainable when contaminants are concentrated in the finer fraction (less than 0.15 mm) of the feed soils. Total Material Mass Balance Data for Condition 3 was as follows (expressed as pounds/hr): Feed soil ranged from 117 to 148 lb/hr. Wash water ranged from 622 to 635 lb/hr. Wasted soil ranged from 112 to 121 lb/hr. Finer slurry ranged from 644 to 653 lb/hr. Closure ranged from 95 to 101 percent with the average closure at 98 percent.	The average PAH REs were 70,83 and 95 percent for Conditions 1, 2 and 3, respectively. The average PCP REs were 76, 92 and 97 percent for Conditions 1, 2 and 3, respectively. Condition 3 physical conditions met the demonstration's project objective criteria.

Source: EPA. 1993g. EPA Risk Reduction Engineering Laboratory (RREL). Mobile Volume Reduction Unit. Applications Analysis Report. Office of Research and Development. August.

TABLE 7-1 (Continued)

SITE DEMONSTRATION TECHNOLOGIES SUMMARY PHYSICAL/CHEMICAL TREATMENT

DEVELOPER/TECHNOLOGY/AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS	DEMONSTRATION RESULTS	REMOVAL EFFICIENCIES
Chemical Waste Management, Inc. PO*WW*ER Technology using evaporation, catalytic oxidation, air scrubbing and condensation EPA/540/AR-93/506	September 1992 CWM Lake Charles Treatment Center Lake Charles, Louisiana	Aqueous wastes, landfill leachate Feed Leachate (mg/L) VOCs 350 - 110,000 SVOCs 6,000 - 23,000 Ammonia 140 - 160 Cyanide 24 - 33 Total metals 4,600 - 5,000	Results showed that the PO*WW*ER system effectively evaporated aqueous waste streams, achieving a total solids concentration ratio of about 32 to 1. Product brine was found to be hazardous based on TCLP results and contained relatively high levels of cyanide. Low levels of metals, below toxicity characteristic leaching procedure (TCLP), was detected in the product condensate.	REs were not determined for VOCs, SVOCs and total metals. Ammonia Evaporation Efficiencies (EEs) ranged from 99.4 to 99.8 percent during unspiked test runs. Cyanide EEs ranged from 81 to 86 percent during unspiked test runs. Spiked test run EEs for ammonia and cyanide showed similar EE results.
Resources Conservation Company Basic Extractive Sludge Treatment (B.E.S.T.) Solvent Extraction System using amine-based solvents to extract organic contaminants EPA/540/AR-92/079	July 1992 Grand Calumet River Gary, Indiana	Sediments Feed Sediment (mg/kg) Sediment A Sediment B PCB 12.1 425 PAH 550 70,900 Oil and grease 6,900 127,000	Treated products compared favorably to the developer's claims of low residual solvent (triethylamine) concentrations; treated sediments exhibited residual solvent concentration of less than 110 mg/kg. The untreated sediment and the treated solids both passed the toxicity characteristic leaching procedure (TCLP) test for metals, therefore significant conclusions on the effects of the B.E.S.T.® process could not be determined.	Sediments A and B REs for total PCBs average greater than 99.6 percent, total PAHs REs were greater than 96 percent and for oil and grease REs were greater than 98.4 percent.

Source: EPA. 1993d. Chemical Waste Management, Inc. PO*WW*ER Technology. Evaporation - Catalytic Oxidation Technology. Applications Analysis Report. Office of Research and Development. September.
EPA. 1993j. Resources Conservation Company. B.E.S.T. Solvent Extraction Technology. Applications Analysis Report. Office of Research and Development. June.

TABLE 7-1 (Continued)

SITE DEMONSTRATION TECHNOLOGIES SUMMARY
PHYSICAL/CHEMICAL TREATMENT

DEVELOPER/TECHNOLOGY/AAR	DATE/SITE	MATRIX/HAZARDOUS CONSTITUENTS	DEMONSTRATION RESULTS	REMOVAL EFFICIENCIES
Peroxidation Systems, Inc. Ultraviolet (UV) Radiation and Hydrogen Peroxide Treatment Technology (Perox-pure™ Chemical Oxidation Technology) EPA/540/AR-93/501	September 1992 Lawrence Livermore National Laboratory (LLNL) Site 300, Tracy, California	<u>Feed Groundwater (ppb)</u> TCE 1,000 PCE 100 The demonstration was conducted in three phases where Phase 1 consisted of eight raw groundwater runs, Phase 2 consisted of four spiked VOC groundwater runs, and Phase 3 consisted of two spiked groundwater runs used to evaluate the quartz tube cleaning effectiveness for Phase 2 and 3, groundwater was spiked with about 200 to 300 ug/L each of chloroform, DCA, and TCA.	The perox-pure™ system waste effluent met the state of California's drinking water action level and EPA drinking water maximum contaminant level criteria at the 95 percent confidence level. Groundwater temperature increased at a rate of 12 degrees F per minute of UV exposure in the treatment system.	REs were not determined for this demonstration. Average raw groundwater REs for TCE and PCE were 99.7 and 97.1 percent, respectively. Average spiked groundwater REs for chloroform, DCA, and TCA were 93.1, 98.3, and 81.8 percent, respectively. TOX REs ranged from 93 to 99 percent.
SBP Technologies, Inc. Membrane Treatment Technology Cross Flow Filtration EPA/540/AR-92/014	October 1991 American Creosote Works Facility, Pensacola, Florida	<u>Feed Groundwater (ppm)</u> Phenol 4.9 PAHs 82.0 PCP 2.4 Individual VOC concentrations in the feed stream were each 50 ug/L. Total VOC feed concentration was about 143 ug/L.	<u>Treated Groundwater (ppm)</u> Permeate Results / Concentrate Results Phenol 3.88 NR PAHs 16.9 NR PCP 1.88 NR The membrane is not expected to remove chemical species with molecular weights less than 200. SBP effectively controlled excessive fouling of the membrane. The system effectively concentrates organic contaminants into a smaller volume concentrate. PAH contaminated wastewater were reduced by over 80 percent. Twenty percent of the feed stream would require further treatment. The average permeate flow rate for the filtration unit was 2.6 gpm.	Overall rejection efficiency of the demonstration was 74 percent over a six day test period.

Source: U.S. Environmental Protection Agency (EPA). 1993i. Peroxidation Systems, Inc. Perox-pure™ Chemical Oxidation Technology. Applications Analysis Report. Office of Research and Development. July.
EPA. 1993k. SBP Technologies, Inc. Membrane Treatment of Wood Preserving Waste Groundwater Technology. Applications Analysis Report. Office of Research and Development. August.

TABLE 7-2

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY PHYSICAL/CHEMICAL TREATMENT

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
AWD Technologies Integrated AquaDetox/ SVE System (IAD/SVES)	The IAD/SVES process is designed to remove volatile organics from soil and groundwater by stripping under a moderate vacuum. Contaminants are retained in a granular activated carbon (GAC) Filter Conventional comparison: Deep well injection would be used to treat contaminated groundwater with low organics, with or without metals. Both processes may need pretreatment to remove suspended solids.	Limiting factors include: • Treatment of low volatility organics may increase steam consumption. • Pretreatment of effluent stream. • Ultimate disposal of GAC residual.	Cost per 1,000 gallons: $0.71 Conventional comparison: Deep well injection costs range from $0.18 to $0.25 per gallon for liquids with a total suspended solids TSS) of 0 to 0.5 percent. For each additional 0.5 percent TSS there is a surcharge of $0.12 to $0.16 per gallon. Cost does not include transportation. Liquids with phased organics will incur a similar surcharge.
CF Systems Organics Extraction Process (OP)	The OP process is designed to remove organics from soils and sediments by solvent extraction. Contaminants may be reclaimed or may require disposal. Conventional comparison: Soils with high organics and low to no metals are normally treated by incineration. The incineration of PCB contaminated soils requires a special permit.	Limiting factors include: • Water may be required to lower viscosities. • Separate process equipment required to treat water streams. • Operational control difficult to maintain. • Possible disposal costs for contaminant residual.	Cost per ton: $148 Costs highly sensitive to initial contaminant concentrations. Conventional comparison: Bulk soils contaminated with organics will cost from $800 to $1100 per ton. Cost includes transportation and disposal of residual ash. PCB contaminated soils can be incinerated within a cost range of $1200 to $2800 per ton.

Source: U.S. Environmental Protection Agency (EPA). 1991a. AWD Technologies Integrated AquaDetox/SVE Technology. Applications Analysis Report. Office of Research and Development. October.
EPA. 1990a. CF Systems Corporation. Solvent Extraction. Applications Analysis Report. Office of Research and Development. August.

TABLE 7-2 (Continued)

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY PHYSICAL/CHEMICAL TREATMENT

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
Dehydro-Tech Corporation Carver-Greenfield Process® (CG)	The CG process separates organic contaminants from soils, sludges, and industrial wastes. Originally developed to dewater municipal sludges. Contaminants may be reclaimed or may require disposal. <u>Conventional comparison:</u> As much free liquid as possible would be removed and then the sludges or solids would be drummed for incineration or stabilized with cement kiln flue dust (CKF). If the organics are high incineration is the best alternative. Liquids extracted from the CG process may require further treatment.	Limiting factors include: • Pretreatment to attain particle sizes of less than 0.25 inch. • Organic stream may require incineration or treatment prior to disposal. • Water stream may require treatment. • Possible disposal costs for contaminant residual.	Cost per ton: $221 <u>Conventional comparison:</u> Incineration of bulk solids and sludges will cost from $800 - $1100 per ton or $0.40 to $0.55 per pound. These costs do not include transportation. CKF costs $10 per ton plus transportation. CKF is usually available within a 150 to 250 mile radius of most potential treatment sites and transportation costs will range from $18 to $20 per ton. A minimum tonnage is required for transportation. Not all CKF suppliers keep a large supply on hand.
NOVATERRA, Inc. (Formerly Toxic Treatments USA, Inc.) In Situ Steam/Hot Air Stripping	Mobile in situ stripping process that uses steam to remove VOCs from soils without excavation. Contaminants may be reclaimed or may require disposal. <u>Conventional comparison:</u> Conventional treatment would be offsite incineration.	Limiting factors include: • Site preparation may be extensive. • Treatment area must be graded to a minimum slope of 1%. • Must have a total site area of 2 acres. • Longer treatment times for high boiling point VOCs • Possible disposal costs for contaminant residual.	Cost range per cubic yard (yd^3): $251 - $317 Based on a total volume of about 9,000 yds^3 not including costs of transportation and disposal of treated residues. <u>Conventional comparison:</u> The cost range for incineration of bulk soils is $800 to $1100 per ton which includes transportation and disposal of residual ash. As the volume of soils and British thermal unit (BTU) value increases, the cost decreases.

Source: U.S. Environmental Protection Agency (EPA). 1992c. Dehydro-Tech Corporation. Carver-Greenfield Process®. Applications Analysis Report. Office of Research and Development. August.
EPA. 1991f. Toxic Treatments USA, Inc. In Situ Steam/Hot-Air Stripping Technology. Applications Analysis Report. Office of Research and Development. March.

TABLE 7-2 (Continued)

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY PHYSICAL/CHEMICAL TREATMENT

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
Terra Vac, Inc. In Situ Vacuum Extraction System	In situ vacuum extraction for removal of VOCs. Conventional comparison: The conventional method would be incineration. Note that the process will require transportation and disposal of the spent carbon and wastewater. Both of these waste streams may require pretreatment.	Limiting factors include: • Contaminant volatility • Soil porosity • Cleanup levels • May involve off-gas and ground water treatment	Cost range per ton: $100 - $250 Conventional comparison: Bulk soil incineration costs range from $800 to $1100 per ton which does not include transportation. As the volume of soil and BTU value increases, the cost will decrease.
Ultrox International Ultraviolet Radiation/ Oxidation Technology (UR/OT)	The UR/OT process uses combinations of ultraviolet radiation, ozone, and hydrogen peroxide to destroy VOCs. Conventional comparison: Due to the high water content and no metals, conventional treatment would include liquid injection incineration or deep well injection.	Limiting factors include: • Pretreatment may be required.	Cost range per 1,000 gallons: $0.25 - $17.00 Conventional comparison: The liquid incineration process costs from $0.18 to $0.23 per pound. The higher the volume treated the lower the cost. Deep well injection costs range from $0.18 to $0.25 per gallon for liquids with a TSS of 0 to 0.5 percent. For each additional 0.5 percent TSS there is a surcharge of $0.12 - $0.16 per gallon. Liquids with phased organics will incur a similar surcharge. These costs do not include transportation. Both processes require installation of wells and pumping equipment.

Source: U.S. Environmental Protection Agency (EPA). 1989d. Terra Vac, Inc. In Situ Vacuum Extraction System. Applications Analysis Report. Office of Research and Development. July.
EPA. 1990d. Ultrox International. Ultraviolet Radiation/Oxidation Technology. Applications Analysis Report. Office of Research and Development. September.

TABLE 7-2 (Continued)

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY
PHYSICAL/CHEMICAL TREATMENT

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
DuPont/ Oberlin Filter Company Microfiltration Technology	Microfiltration technology removes small (>0.1 micron) particulate contaminants from aqueous wastes. Conventional comparison: Due to the high liquid and metals content, the conventional treatment would be deep well injection. However, as the Total Suspended Solids (TSS) increases so does the cost.	Limiting factors include: • Pretreatment to convert metals. • Optimal operating conditions (pH, additive dosages, blowdown time and pressure) must be determined before treatment.	Cost per gallon: $0.40 per gallon Capital costs for a unit treating about 500,000 gallons per year is $370,000 including site preparation costs. Conventional comparison: Deep well injection costs range from $0.18 to $0.25 per gallon for liquids with a TSS of 0 to 0.5 percent. For each additional 0.5 percent TSS there is a surcharge of $0.12 to $0.16 per gallon. Cost does not include transportation.
EPOC Water, Inc. Microfiltration Technology	Treats water or sludge contaminated with heavy metals by microfiltration. Particle sizes greater than 0.1 micron can be removed. Conventional comparison: Due to the high liquid and metals content, the conventional treatment would be deep well injection. However, as the total suspended solids increases so does the cost.	Limiting factors include: • Streams with dissolved metals require precipitation pretreatment.	Cost range per 1,000 gallons: $50 - $150 Low cost end based on treatment unit processing 3,000 gallons per hour. Conventional comparison: Deep well injection costs range from $0.18 to $0.25 per gallon for liquids with a TSS of 0 to 0.5 percent. For each additional 0.5 percent there is a surcharge of $0.12 to $0.16 per gallon. Cost does not include transportation.

Source: U.S. Environmental Protection Agency (EPA). 1991d. E.I. DuPont De Nemours & Company/Oberlin Filter Company. Membrane Microfiltration Technology. Applications Analysis Report. Office of Research and Development. October.
EPA. 1993h. EPOC Water, Inc. Microfiltration Technology. Draft Applications Analysis Report. Office of Research and Development. May.

TABLE 7-2 (Continued)

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY PHYSICAL/CHEMICAL TREATMENT

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
Toronto Harbour Commissioners Soil Recycle Treatment Train	Treatment train for removal of inorganic and organic contaminants, involving soil washing, chelation, and a bioslurry process. <u>Conventional comparison:</u> Conventional treatment would include incineration for the organics and low metal content or CKF for high metal content and low organic content.	Limiting factors include: • Soil fines should not exceed 30 to 35 percent of the feed. • Soils high in metals may require multiple passes through the system.	Cost per ton: $219 <u>Conventional comparison:</u> CKF costs $10 per ton plus transportation. CKF is usually available within 150 to 250 miles radius of most potential treatment sites and transportation costs will range from $18 to $20 per. A minimum tonnage charge is required for transportation. Bulk soil incineration costs range from $800 to $1100 per ton or $0.40 to $0.55 per pound. These costs include transportation and disposal of residual ash.
EPA RREL Mobile Volume Reduction Unit (VRU)	The VRU process removes organic and inorganic contaminants by dissolving them or by suspending them in a wash solution. <u>Conventional comparison:</u> Conventional treatment would include incineration. At present, only one incinerator is permitted to burn dioxin or its precursors.	Limiting factors include: • Soil fines should not exceed 30 to 40 percent. • May require pretreatment. • Residuals may be hazardous and may require further treatment	Cost per ton: $130 <u>Conventional comparison:</u> Bulk soil incineration costs range from $800 to $1100 per ton or $0.40 to $0.55 per pound. These costs do not include transportation. If the waste contains PCP, a dioxin precursor, then incineration will cost from $8 to $25 per pound depending on the presence of additional organics and/or metals and additional handling requirements by the disposal facility.

Source: U.S. Environmental Protection Agency (EPA). 1993n. Toronto Harbour Commissioners. Soil Recycle Treatment Train. Draft Applications Analysis Report. Office of Research and Development. April.
EPA. 1993g. EPA Risk Reduction Engineering Laboratory (RREL). Mobile Volume Reduction Unit. Draft Applications Analysis Report. Office of Research and Development. August.

TABLE 7-2 (Continued)

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY PHYSICAL/CHEMICAL TREATMENT

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
Chemical Waste Management PO*WW*ER Technology	PO*WW*ER technology removes volatile, semivolatile, and other contaminants by evaporation, followed by catalytic oxidation, scrubbing, and condensation. System is best suited for concentrated wastewaters. Conventional comparison: Conventional treatment would include liquid injection incineration or deep well injection. As the volume of total suspended solids is increases, deep well injection becomes less practical.	Limiting factors include: • Total contaminant loading • Not cost effective in treating dilute streams	Cost per 1,000 gallons: $100 Based on 50-gallon-per-minute treatment system. Conventional comparison: The liquid injection incineration cost ranges from $0.18 to $0.23 per pound for high water content wastes. Reactive liquids will increase the cost to $0.43 per pound. The higher the volumes treated the lower the cost. These costs do not include transportation. Deep well injection costs range from $0.18 to $0.25 per gallon for liquids with a TSS of 0 to 0.5 percent. For each additional 0.5 percent TSS there is a surcharge of $0.12 to $0.16 per gallon. Liquids with phased organics will incur a similar surcharge.
Resources Conservation Company B.E.S.T. System	Solvent extraction technology that exploits the variable solubility characteristics of organic amines at varying temperatures. Conventional comparison: Conventional treatment would be by incineration. The process may require further treatment of residual solvents.	Limiting factors include: • Prescreening to attain particle size < 0.5 inch • Full-scale system treats sludges only	Cost range per ton: $172 - $192 Based on an on-line factor of 60 to 80 percent. Conventional comparison: Bulk soil incineration costs range from $800 to $1100 per ton or $0.40 to $0.55 per pound. Treatment of PCB contaminated soils requires a permit and the cost increases to $1200 to $2800 per ton. These costs do not include transportation.

Source: U.S. Environmental Protection Agency (EPA). 1993d. Chemical Waste Management, Inc. PO*WW*ER Technology. Draft Applications Analysis Report. Office of Research and Development. February.
EPA. 1993j. Resources Conservation Company. B.E.S.T. Solvent Extraction Technology. Applications Analysis Report. Office of Research and Development. June.

TABLE 7-2 (Continued)

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY PHYSICAL/CHEMICAL TREATMENT

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
Peroxidation, Systems, Inc. Perox-pure™ Chemical Oxidation Technology	Perox-pure™ is designed to destroy organic contaminants found in contaminated water through the addition of hydrogen peroxide and sulfur** to feed water. The feed water is then exposed to ultraviolet radiation in a reactor vessel. Perox-pure™ has achieved chlorinated organic contaminant removal efficiencies ranging from 97.1 to 99.7 percent conventional comparison. Conventional comparison Due to a high water content, conventional treatment would include liquid injection incineration or deep well injection. As the total suspended solids increase, the cost for disposal increases. At present, only one incinerator is permitted to burn dioxin or its precursors.	Limiting factors include: · pH dependent · A filter cartridge replacement and disposal · Wastewater discharge Feed material should be: · Slightly acidic at a pH equal to 5.0 · Free of suspended solids greater than 3 micrometers in size	Case 1 Gallons per minute (gpm) — Costs per 1,000 gallons treated 10 — $19 50 — $5 100 — $5 Based on groundwater containing five organic contaminants, with three contaminants difficult to oxidize. Assumes continuous flow cycle, 24 hours per day, 7 days per week. Case 2 gpm — Costs per 1,000 gallons treated 10 — $15 50 — $3 100 — $2 Based on groundwater containing two organic contaminants which are easy to oxidize. Assumes continuous flow cycle. Conventional comparison: The liquid injection incineration cost ranges from $0.18 to $0.23 per pound for high water content wastes. Reactive liquids will increase the cost to $0.43 per pound. The higher the volumes treated the lower the cost. These costs do not include transportation. Deep well injection costs range from $0.18 to $0.25 per gallon for liquids with a TSS of 0 to 0.5 percent. For each additional 0.5 percent TSS there is a surcharge of $0.12 to $0.16 per gallon. Liquids with phased organics will incur a similar surcharge.

Source: U.S. Environmental Protection Agency (EPA). 1993i. Peroxidation Systems, Inc. Perox-pure™ Chemical Oxidation Technology. Applications Analysis Report. Office of Research and Development. July.

TABLE 7-2 (Continued)

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY PHYSICAL/CHEMICAL TREATMENT

TECHNOLOGY	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
SBP Technologies, Inc. (SBP) Membrane Treatment Technology	SBP's cross-filtration membrane technology is designed to remove organic contaminants found in contaminated water. This process reduces the volume of waste through separating and concentrating high molecular weight organic contaminants with a molecular weight greater than 200. <u>Conventional comparison</u> Due to a high water content, conventional treatment would include liquid injection incineration or deep well injection. As the total suspended solids increase, the cost for disposal increases. At present, only one incinerator is permitted to burn dioxin or its precursors.	Limiting factors include: · Removing organic compounds with a molecular weight less than 200 · Removal of waste soluble organic compounds (i.e. phenolics) · Wastewater discharge · About 24 gallons per minute (gpm) can be treated, if conditions are optimal. Feed material should be: · Diluted to a predetermined level which allows discharge of the permeate without further treatment · Free of oil and suspended solids · Operating with a feed water chemical oxygen demand between 100-500 mg/L.	<u>Conventional comparison:</u> The liquid injection incineration cost ranges from $0.18 to $0.23 per pound for high water content wastes. Reactive liquids will increase the cost to $0.43 per pound. The higher the volumes treated the lower the cost. These costs do not include transportation. Deep well injection costs range from $0.18 to $0.25 per gallon for liquids with a TSS of 0 to 0.5 percent. For each additional 0.5 percent TSS there is a surcharge of $0.12 to $0.16 per gallon. Liquids with phased organics will incur a similar surcharge. The maximum assumed flow rate is about 24 gpm. Total costs are based upon 1,000 gallons of contaminated water treated (with and without further effluent treatment and disposal costs). Projected costs are as follows (per 1,000 gallons):

	24 gpm	12 gpm	7.2 gpm
With treatment	$228-$522	$456-$1,044	$760-$1,739
Without treatment	About $222	About $444	About $739

Source: EPA. 1993k. SBP Technologies, Inc. Membrane Treatment of Wood Preserving Waste Groundwater Technology. Applications Analysis Report. Office of Research and Development. August.

8.0 MATERIALS HANDLING

Materials handling is an integral part of the remediation process involving physical or chemical processes which facilitate use of the remediation technology. This type of technology is particularly important where other stand-alone technologies may be inefficient or impractical; its purpose is to increase the efficiency and effectiveness of other remediation processes. Treatability studies and field investigations are a necessary precursor in order to determine the type of materials handling technology required for the wastes present.

Additional information on materials handling is found in EPA's Engineering Bulletin number EPA/540/2-91/023.

8.1 APPLICABLE SITE DEMONSTRATIONS

Three materials handling technologies have been demonstrated under the SITE Program. Table 8-1 (following this section) summarizes SITE demonstration costs and applications.

U.S. EPA Air and Energy Engineering Research Laboratory (AEERL) in conjunction with the U.S. RREL, U.S. EPA Region 9, and the California Department of Health Services (CDHs) sponsored a SITE demonstration which was demonstrated in July 1990, at the McColl Superfund site in Fullerton, California. EERL, RREL, EPA Region 9 and CDH evaluated a vapor-suppressing foam and a temporary, contained, atmosphere-controlled building to contain VOC vapor and sulfur dioxide (SO_2) emissions during excavation of contaminated soils. In this demonstration, a foam was applied to soil before, during, and after excavation activities to reduce emissions emanating immediately from the exposed surfaces. In addition, a large, temporary structure enclosed the excavation area and equipment, and all air emissions were passed through emissions control equipment including a scrubber prior to release into the atmosphere.

Accutech Remedial Systems, Inc. (Accutech) developed the Pneumatic Fracturing Extraction^{SM} and Hot Gas Injection Process, which was demonstrated in the summer 1992, at a New Jersey State Superfund site in Hillsborough, New Jersey. Accutech's pneumatic fracturing extraction technology was demonstrated at an industrial site with TCE contamination in the vadose zone. This technology involves forcing compressed gas into the subsurface by means of specially-constructed wells in order to create a fracture network. Use of this technology may increase the permeability of the subsurface and the radius of influence of each well. U.S. EPA RREL in conjunction with the University of Cincinnati demonstrated the selective hydraulic fracturing of contaminated, low permeability soils. For this technology, water is pumped into a sealed well until fractures are induced in the subsurface. At that time, a slurry of coarse-grained sand and guar gum gel is injected to fill the growing fractures. An enzyme additive decomposes the gel and the sand remains to support the fracture opening. These induced fractures increase the effectiveness of treatment technologies such as vapor extraction, in situ bioremediation, and pump-and-treat systems.

8.2 TREATMENT TRAIN AND TECHNOLOGY ADVANCEMENTS

Materials handling technologies are, by definition, a part of a treatment train (i.e., a series of technologies which sequentially act on the waste or a subcomponent of the waste at a site). The technologies demonstrated in the SITE Program are examples of both treatment enhancement (fracturing) and control of remediation parameters (temporary building and foam). In both cases, these technologies may provide a solution to a remediation problem that otherwise could not be handled with a conventional approach.

As remediation of certain hazardous wastes becomes better understood, the development of additional materials handling technologies can extend the effectiveness of remediation technologies to wastes which are presently more difficult to treat. The pneumatic and hydraulic fracturing technologies have increased the range of effectiveness of in situ technologies in this manner. Further advances in the area of materials handling are greatly needed to reduce costs as well as increase effectiveness of existing remediation techniques.

TABLE 8-1

SITE DEMONSTRATION TECHNOLOGY APPLICATIONS AND COST SUMMARY MATERIALS HANDLING

DEVELOPER/ TECHNOLOGY/AAR	DATE/SITE	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
EPA Air and Energy Engineering Research Laboratory (AEERL), EPA Risk Reduction Engineering Laboratory (RREL), EPA Region 9, and the California Department of Health Services (DHS) Excavation Techniques and Foam Suppression Methods EPA/540/AR-92-015	July 1990 McColl Superfund site, Fullerton, California	Emissions control during soil excavation. Technology involves temporary enclosure with exhaust air treatment system, vapor-suppressing soil surface foam to contain VOC vapor and sulfur dioxide (SO_2) emissions during excavation of contaminated soils. <u>Conventional comparison:</u> No comparable technology exists for this process because it is an add-on. It was used to alleviate technical problems with an existing method.	Limiting factors include: • Adequate exhaust air flow and filtration rate, and foam-to-soil-contaminant compatibility, must be determined prior to application. • Exhaust from diesel engines generated within the enclosure may exceed the process capacity of the exhaust air treatment unit. • Suppression foam may get slippery, increasing work hazards.	Cost per ton based on excavation of 116,700 tons: $593 with an equipment/services purchase option. Total cost $69.2 million. $637 with an equipment/services lease option. Total cost $74.3 million. Cost estimates reflect a 6.4 year remediation period, which is based on a process rate of 100 tons/day. <u>Conventional comparison:</u> No comparison available.
Accutech Remedial Systems, Inc. Pneumatic Fracturing Extraction[SM] and Hot Gas Injection EPA/540/AR-93/509	Summer 1992 New Jersey Environmental Cleanup Responsibility Act site, Hillsborough, New Jersey	Designed to assist removal of trichloroethene (TCE) and volatile organic compounds (VOCs) from vadose subsurface zones by pneumatic fracturing and hot gas injection, increasing permeability, and thus enhancing treatment. <u>Conventional comparison:</u> No comparable technology exists for this process because it is an add-on. It was used to alleviate technical problems with an existing method.	Limiting factors include: • Ambient air and ground temperature • Presence of water in the vadose zone • VOC solubility and vapor pressures may affect removal efficiency	Cost per pound of VOCs: $130 (Based on TCE removal efficiency) Exact costs highly dependent on specific applications. <u>Conventional comparison:</u> No comparison available.

Source: U.S. Environmental Protection Agency (EPA). 1992d. EPA Region IX, AEERL, SITE, and California Department of Health Services. Demonstration of a Trial Excavation at the McColl Superfund Site. Applications Analysis Report. Office of Research and Development. October.
EPA. 1993a. Accutech Remedial Systems. Accutech Pneumatic Fracturing Extraction and Hot Gas Injection, Phase 1. Applications Analysis Report. Office of Research and Development. July.

TABLE 8-1 (Continued)

SITE DEMONSTRATION TECHNOLOGY APPLICATION AND COST SUMMARY MATERIALS HANDLING

DEVELOPER/ TECHNOLOGY/AAR	DATE/SITE	APPLICATION/CONVENTIONAL	LIMITING FACTORS	COST INFORMATION/CONVENTIONAL
EPA Risk Reduction Engineering Laboratory and the University of Cincinnati Hydraulic fracturing of contaminated soil EPA/540/5-91/006a	September 1992 Integrated with other remediation techniques at sites in Oak Brook, Illinois and Dayton, Ohio	Designed for use in low permeability silty clays contaminated with organic compounds. A hydraulic fracture is induced in the soil which enhances other in situ remediation techniques such as vapor extraction, pump-and-treat, and bioremediation. Additives may be used in fracturing which enhance other treatment processes. Conventional comparison: No comparable technology exists for this process because it is an add-on. It was used to alleviate some technical problem with an existing method.	Limiting factors include: • Direction and extent of fracture propagation difficult to control. • May require multiple fracture emplacement for maximum technology effectiveness.	Cost range for creating a typical fracture: $950 - $1,425 Capital cost of equipment is $92,000. Rental cost is $1,000 per day. Conventional comparison: No comparison available.

Source: U.S. Environmental Protection Agency (EPA). 1991e. RREL and the University of Cincinnati. Hydraulic Fracturing of Contaminated Soil. Applications Analysis Report. Office of Research and Development. May.

9.0 RADIOACTIVE WASTE TECHNOLOGY

The unique problems associated with the handling and disposal of radioactive waste in any type of media pose a formidable challenge to any technology. Radioactive waste must be liberated from its host media, concentrated, stabilized, and disposed of or recycled. Technologies in the SITE Program indicate that, since radionuclides cannot be made nonhazardous, the most desirable methods for handling and disposing of radioactive waste involve concentration and subsequent treatment using S/S technologies. S/S technologies are described in Section 4.0.

Two radionuclide technologies have been accepted into the SITE Program, and each will be demonstrated in early 1994. The TechTran chemical precipitation, physical separation, and binding process technology will treat uranium-contaminated pond water at a uranium mine in south Texas using a radionuclide concentration technique. A similar technology, the Filter-Flow heavy metals and radionuclide sorption method, will be used to treat groundwater at the Department of Energy (DOE) Rocky Flats, Colorado, facility.

Because no demonstration projects have been completed at present, no further information is available on technologies for the treatment of radioactive wastes.

10.0 THE SITE PROGRAM--PRESENT AND FUTURE

The SITE Program is a key element in EPA's efforts to increase the availability and use of innovative technologies for remediation of the nation's hazardous waste sites. This section highlights the SITE Program's accomplishments to date and discusses issues pertinent to the future of the program and removal and remediation technologies.

10.1 SITE PROGRAM ACCOMPLISHMENTS

The major accomplishments for the SITE Program since its inception in 1986 include:

- **Increased awareness and acceptability**
  Innovative technology use has increased in both the public and private sectors. At Superfund sites, the number of innovative technologies selected for remediation now equals the number of conventional technologies selected.

- **Documented cost savings**
  The SITE Program has shown that innovative technology usage has resulted in significant cost savings compared to conventional technologies. In an analysis of technology costs in four EPA regional offices, selection of innovative technologies resulted in average cost savings of $ 21 million, or 62% per site.

- **Increased business for developers**
  Technology developers have reported an increase in business inquiries resulting from their participation in the SITE Program. Developers who have completed SITE demonstrations reported 533 contract awards (395 non-Superfund plus 138 Superfund) attributable to SITE Program participation.

- **Expanded technology transfer**
  EPA's Center for Environmental Research Information (CERI) has distributed over 200,000 copies of reports documenting innovative technologies in the SITE Program. Users include consultants, state and local governments, EPA and other federal officials, universities, industries, and private citizen groups.

- **Continued growth**
  More than 60 demonstrations of innovative remediation technologies have been completed to date. Over 100 developers are participating in the SITE Program.

10.2 FUTURE CHALLENGES FOR THE SITE PROGRAM

One goal of the SITE Program is to promote innovative technologies with marketable futures. Some technologies in the program have passed the innovative stage and are now accepted as applicable standards. One of these technologies, Terra Vac's soil vapor extraction (SVE), is now considered a standard option for removal of VOCs from the unsaturated zone. As a testimonial to the strength of the market, many other companies have developed and are now marketing SVE technologies, some with enhancements such as hot air injection combined with groundwater extraction. Several of these SVE companies are participants in the SITE Program.

Another example of SITE technology marketability is the Shirco Infrared Incineration technology. Although the company which owns and markets this technology has changed, the technology and its application have remained basically the same: use of electrically-powered silicon carbide rods to heat organic wastes to combustion temperatures. The Shirco Infrared system has been and continues to be used at numerous Superfund sites.

To continue successful development and evaluation of innovative treatment methods, the SITE Program must be responsive to the changing market needs. Important challenges still facing the SITE demonstration program are described below.

10.2.1 Providing Additional Cost and Performance Data

The SITE demonstration program uses cost and performance data collected during each technology demonstration to generate accurate and independent cost estimates. Since a primary goal of promoting technology innovation is reducing overall remediation costs, SITE cost estimates provide decision-makers with information central to their search for cost-effective treatment solutions. In addition, well-developed cost estimates provide technology developers and end users with analytical insights useful in optimizing remediation technologies. Finally, SITE cost estimates are used to help innovative technology developers enter capital markets by helping match investors' funds with proven, cost-effective technologies.

10.2.2 Pinpointing Future Innovative Technology Needs

The science of site investigation has advanced dramatically in the past twenty years. Advancements in field detection equipment and laboratory analyses have revealed new information about the problems at waste sites. These advancements, coupled with the experience gained from the numerous sites under investigation, have generated a need for new, innovative technologies.

One of the critical needs for remediation technology is for methods to accelerate aquifer cleanup. By nature, groundwater is a slow-moving, slow-to-change medium. Groundwater contamination may consist of multi-phase contaminant plumes, light non-aqueous phase liquids (LNAPLS), and dense non-aqueous phase liquids (DNAPLS), which can potentially move in different directions. New technologies are needed to control and remediate these diverse problems.

Some of the most important technology breakthroughs are anticipated in chemical conversion methodologies. Technologies which rely on chemical conversion of the contaminant species rather than destruction or stabilization will end the remediation process at treatment. Conversion eliminates the need for further environmental engineering, containment, or control of waste products or byproducts (for example, incineration ash, solidified waste material). These technologies are also at the core of in-line, chemical conversion process research that could eventually supply solutions for re-engineered processes to reduce waste material generation. The need for recycling and reuse technologies will help drive the development of chemical conversion technologies because of their potential for cost savings and for limiting short- and long-term liability.

10.2.3 Technologies on the Horizon

As a result of evaluating field demonstrations of innovative remediation technologies each year, in addition to providing financial assistance to developers of emerging technologies, the SITE Program maintains a unique position in the hazardous waste remediation marketplace. Together with EPA's Technology Innovation Office, SITE provides information on technology gaps and upcoming technical advancements.

A number of promising technologies based on sound scientific principles, but lacking engineering and performance documentation, are appearing on the horizon. Some of these promising technologies are described below. These technologies are being researched and developed under the SITE Emerging Technologies Program, and by the U.S. Department of Energy, and others. It is likely that field demonstrations may occur within one to two years.

- **In situ steam/hot air extraction** - The use of steam or hot air as an extraction medium has been proposed for many years. This technology forces steam or hot air through injection wells to remove SVOCs in addition to VOCs. Challenges remaining for this technology include: harnessing and controlling the steam, decreasing rather than increasing the volume of waste, and collecting and disposing of the contaminated material. The application of this technology to unsaturated soil has improved the prospects for this technology.

- **Bioremediation** - Various bioremediation technologies have entered the SITE Program. In some instances, biodegradation is used with other technologies to accomplish a greater total removal efficiency of organic contaminants. Difficulties associated with biodegradation include: determining which microorganisms can break down specific organic compounds, culturing the microorganism in a favorable environment which provides nutrients and promotes growth, and the length of time required to completely degrade an organic compound to acceptable levels. Using methanotrophic bacteria to degrade chlorinated volatile organic compounds in soil and sludges is a new technology in the SITE Program. Other biodegradation technologies include: bioslurry (bionet) and bioreactor techniques which can be combined with pre-washing or flushing soil, bioscrubbers for air emissions control, and bioreactors combined with ultrafiltration membranes for treatment of aqueous wastes. Enhancements under investigation include: hydrogen peroxide and other electron acceptors and air sparging to improve treatment, co-metabolic processes and consortia, nitrate enhancement, and anaerobic or sequential aerobic/anaerobic degradation.

- **Electroremediation techniques** - Techniques such as electro-osmosis, electromigration, and electrophoresis through electrokinetics, and electrochemical oxidation are used in situ to treat contaminated soils, sludges, and aqueous media. In electrokinetics, direct current flowing from positive to negative electrodes in combination with pore-conditioning fluids circulating in the soil provide in-situ removal of contaminants. The contaminants are directly deposited on the electrodes or removed from the conditioning fluid through a purification process. Electrokinetics can effectively increase the flow of fluids and/or gases within formations where intrinsic permeability is very low. In electrochemical oxidation, electrodes are used to generate hydrogen peroxide from contaminated groundwater. The hydrogen peroxide catalytically decomposes on iron particles to form hydroxyl radicals, which then react with organic contaminants. This technology performs chemical conversion, thereby destroying the contaminants.

- **Hydrogen reduction** - This technology is based on the gas-phase, thermochemical reaction of hydrogen with organic and chlorinated organic contaminants at 850 °C or higher. This technology chemically reduces organic compounds to smaller, lighter, chained hydrocarbons. The technology can be used with thermal desorption, and may be more cost-effective than traditional thermal destruction or incineration.

- **Advanced physical/chemical treatment** - Many new technologies are under development in the area of physical and/or chemical treatment of contaminated matrices. Many of these technologies remain unproven or are in developmental phases. Using these technologies can expand in-situ cleanup opportunities to medium- and low-permeability soils, semivolatile organic compounds (SVOCs) in addition to volatile organic compounds (VOCs), and areas where excavation costs are prohibitive or excavation is infeasible. These advanced physical/chemical treatment technologies include:

  - hydrofracturing and pneumatic fracturing to improve in situ permeability through injection of pressurized fluids or air;
  - air sparging to improve in-situ bioremediation or to remove contaminants from the subsurface;
  - directional drilling to place wells under surface structures or in horizontal positions;
  - radio frequency heating using electromagnetic energy to volatilize contaminants;
  - high energy electron beam irradiation to destroy organic contaminants in a variety of waste matrices;
  - regenerable adsorption materials which can adsorb 5 to 10 times the capacity of granular activated carbon for treatment of aqueous matrices;
  - cross-flow pervaporation systems which remove VOCs from aqueous matrices;
  - in-situ reaction walls which funnel groundwater through permeable gates, where treatment occurs via reductive dehalogenation or other techniques;
  - in-situ photocatalytic oxidation of various wastes in soils, sediments, or sludges.

- **Treatment trains and combination technologies** -A treatment train is a sequential combination of technologies which treat recalcitrant waste matrices more effectively than any single technology could. Treatment trains of innovative technologies can be less costly and more effective in achieving treatment goals than conventional technologies. The "Lasagna" process is an example of several innovative technologies used in concert to treat contaminants in situ in less permeable soils including clays and silts. Electro-osmosis first drives contaminants out of soil pores and into treatment zones created by hydrofracturing, pneumatic fracturing, or trenching. Contaminants are then treated in treatment zones by biodegradation, catalytic dechlorination, or adsorption. Electrodes for the electro-osmosis system can be placed by sheet piling, hydrofracturing, or horizontal drilling. Further development of this process is proceeding under a Cooperative Research and Development Agreement with Monsanto Company, DuPont, General Electric, and EPA.

SITE PROGRAM DOCUMENTS REFERENCED

U.S. Environmental Protection Agency (EPA).1989a. American Combustion, Inc. *PYRETRON® Destruction System. Applications Analysis Report.* Office of Research and Development. EPA/540/A5-89/008. June.

EPA. 1989b. Hazcon, Inc. *HAZCON Solidification Process, Douglasville, Pennsylvania. Applications Analysis Report.* Office of Research and Development. EPA/540/A5-89/001. May.

EPA. 1989c. Shirco Infrared Systems, Inc. *Infrared Incineration System. Applications Analysis Report.* Office of Research and Development. EPA/540/A5-89/010. June.

EPA. 1989d. Terra Vac, Inc. *In Situ Vacuum Extraction System. Applications Analysis Report.* Office of Research and Development. EPA/540/A5-89/003. July.

EPA. 1990a. CF Systems Corporation. *Solvent Extraction. Applications Analysis Report.* Office of Research and Development. EPA/540/A5-90/002. August.

EPA. 1990b. International Waste Technologies Corp./Geo-Con, Inc. *In Situ Stabilization/Solidification. Applications Analysis Report.* Office of Research and Development. EPA/540/A5-89/004. August.

EPA. 1990c. Soliditech, Inc. *Solidification/Stabilization Process. Applications Analysis Report.* Office of Research and Development. EPA/540/A5-89/005. September.

EPA. 1990d. Ultrox International. *Ultraviolet Radiation/Oxidation Technology. Applications Analysis Report.* Office of Research and Development. EPA/540/A5-89/012. September.

EPA. 1991a. AWD Technologies. *Integrated AquaDetox/SVE Technology. Applications Analysis Report.* Office of Research and Development. EPA/540/A5-91/002. October.

EPA. 1991b. Biotrol, Inc. *Biological Aqueous Treatment. Applications Analysis Report.* Office of Research and Development. EPA/540/A5-91/001. September.

EPA. 1991c. Chemfix Technologies, Inc. *Solidification/Stabilization Process. Applications Analysis Report.* Office of Research and Development. EPA/540/A5-89-011. May.

EPA. 1991d. E.I. DuPont De Nemours & Company/Oberlin Filter Company. *Membrane Microfiltration Technology. Applications Analysis Report.* Office of Research and Development. EPA/540/A5-90/007. October.

EPA. 1991e. EPA Risk Reduction Engineering Laboratory (RREL) and the University of Cincinnati. *Hydraulic Fracturing of Contaminated Soil. Applications Analysis Report.* Office of Research and Development. EPA/540/5-91/006a. May.

EPA. 1991f. Toxic Treatments USA, Inc. *In Situ Steam/Hot-Air Stripping Technology. Applications Analysis Report.* Office of Research and Development. EPA/540/A5-90/008. March.

EPA. 1992a. Babcock & Wilcox. *Cyclone Furnace Vitrification Technology. Applications Analysis Report.* Office of Research and Development. EPA/540/AR-92/017. August.

EPA. 1992b. BioTrol, Inc. *Soil Washing System. Applications Analysis Report.* Office of Research and Development. EPA/540/A5-91/003. February.

EPA. 1992c. Dehydro-Tech Corporation. *Carver-Greenfield Process®. Applications Analysis Report.* Office of Research and Development. EPA/540/AR-92/002. August.

EPA. 1992d. EPA Region IX, EPA Air and Energy Engineering Research Laboratory (AEERL), EPA Superfund Innovative Technology Evaluation (SITE) Program, and California Department of Health Services (DHS). *Demonstration of a Trial Excavation at the McColl Superfund Site. Applications Analysis Report.* Office of Research and Development. EPA/540/AR-92/015. October.

EPA. 1992e. Horsehead Resource Development Company, Inc. *Flame Reactor Technology. Applications Analysis Report.* Office of Research and Development. EPA/540/A5-91/005. May.

EPA. 1992f. Retech, Inc. *Plasma Centrifugal Furnace. Applications Analysis Report.* Office of Research and Development. EPA/540/A5-91/007. June.

EPA. 1992g. Silicate Technology Corporation. *Solidification/Stabilization Technology for Organic and Inorganic Contaminants in Soils. Applications Analysis Report.* Office of Research and Development. EPA/540/AR-92/010. December.

EPA. 1992h. Roy F. Weston, Inc. *Low Temperature Thermal Treatment (LT³®) System. Draft Applications Analysis Report.* Office of Research and Development. December.

EPA. 1993a. Accutech Remedial Systems. *Pneumatic Fracturing Extraction and Hot Gas Injection, Phase I. Applications Analysis Report.* Office of Research and Development. July.

EPA. 1993b. BioGenesis Enterprises, Inc. *BioGenesis℠ Soil Washing Technology. Innovative Evaluation Report.* Office of Research and Development. EPA/540/R-93/510. September.

EPA. 1993c. Canonie Environmental Services Corporation. *Low Temperature Thermal Treatment Aeration (LTTA®) Technology. Draft Applications Analysis Report.* Office of Research and Development. January.

EPA. 1993d. Chemical Waste Management, Inc. *PO*WW*ER Technology. Applications Analysis Report.* Office of Research and Development. September.

EPA. 1993e. Chemical Waste Management, Inc. *X*TRAX™ Model 200 Thermal Desorption System. Draft Applications Analysis Report.* Office of Research and Development. September.

EPA. 1993f. ECOVA Corporation. *Bioslurry Reactor. Draft Applications Analysis Report.* Office of Research and Development. March.

EPA. 1993g. EPA Risk Reduction Engineering Laboratory (RREL). *Mobile Volume Reduction Unit. Draft Applications Analysis Report.* Office of Research and Development. August.

EPA. 1993h. EPOC Water, Inc. *Microfiltration Technology. Draft Applications Analysis Report.* Office of Research and Development. May.

EPA. 1993i. Peroxidation Systems, Inc. *Perox-Pure™ Chemical Oxidation Technology. Applications Analysis Report.* Office of Research and Development. EPA/540/AR-93/501. July.

EPA. 1993j. Resources Conservation Company. *B.E.S.T. Solvent Extraction Technology. Applications Analysis Report.* Office of Research and Development. EPA/540/AR-92/079. June.

EPA. 1993k. SBP Technologies, Inc. *Membrane Treatment of Wood Preserving Waste Groundwater. Applications Analysis Report.* Office of Research and Development. EPA/540/AR-92/014. August.

EPA. 1993l. SoilTech ATP Systems, Inc. *Anaerobic Thermal Processor. Draft Applications Analysis Report.* Office of Research and Development. March.

EPA. 1993m. The Superfund Innovative Technology Evaluation (SITE) Program. *Technology Profiles, Sixth Edition.* Office of Research and Development. EPA/540/R-93/526. November.

EPA. 1993n. Toronto Harbour Commissioners. *Soil Recycle Treatment Train. Draft Applications Analysis Report.* Office of Research and Development. April. Section 7-4, 7-11

EPA. 1993o. Vendor Information System for Innovative Treatment Technologies (VISITT) Database. Version 2.0. June.

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